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Attentional Contributions to Social Cognition and Social Behaviors: Implications for Autism Spectrum Disorder and Attention-Deficit/ Hyperactivity Disorder

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Social participation requires the processing and utilization of visual information and early interactions with the environment can shape neurological development, setting children on a typical or atypical developmental trajectory. In the case of autism spectrum disorders (ASD), early manifestations of atypical visual, social attention (i.e., joint attention) are one of the earliest markers of atypical development and one of the most influential processes contributing to development in other domains (e.g., language). The current study aimed to assess multiple aspects of low-level visual attention, through a modified Posner-paradigm, that may contribute to social behavior and social cognition. Behavioral reaction time (RT) and eye-movements were tracked through an experimental task, for individuals (ages 8 to 18 years) with typical development (TD), ASD, and attention-deficit/hyperactivity disorder (ADHD), to measure how participants perceived and responded to directionally-meaningful visual information; social functioning was measured using standardized and experimental assessments of social behavior and cognition. Behavioral results indicated that the ASD group demonstrated *more* difficulty overriding and reallocating their attention when it was directed to an incorrect location; this finding was exaggerated for non-social (arrow) cues, but decreased for social (face) cues, when compared to their TD peers. Evidence also suggested reduced attentional engagement in the visual cues, as supported by both RT and eye-tracking evidence, when comparing the ASD group to both comparison groups. The contributions of social salience, response salience, and visual-field laterality were also assessed. The ADHD group, despite characteristic variability in RT, performed most similarly to their TD peers. The results from this study indicate that reduced engagement in visual information may limit individuals with ASD's ability to identify relevant visual stimuli and that, once engaged, individuals with ASD may struggle to use this information to efficiently modify their behavioral response. Encouragingly, once attention is engaged, individuals with ASD appear able to interpret the directional cues as meaningful. These findings in the context of a controlled, experimental paradigm are likely exacerbated in the complex, dynamic nature of real-life social situations and implications for early intervention were discussed.

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Implications for Autism Spectrum Disorder and Attention-Deficit/Hyperactivity Disorder

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Attentional Contributions to Social Cognition and Social Behaviors:

Implications for Autism Spectrum Disorder and Attention-Deficit/Hyperactivity Disorder

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Table of Contents

Attentional Contributions to Social Cognition and Social Behaviors:

Implications for Autism Spectrum Disorder and Attention-Deficit/Hyperactivity Disorder

Social interactions, and what one learns from social interactions, are a driving force in development and are the crux of many daily activities. Children, in particular, use social interactions to gather information from their environment and to engage in critical learning opportunities. Joint attention, defined as the ability to coordinate attention with another person in reference to an event or object in the environment, is a social process children use to learn about their environments (Kaplan & Hafner, 2006). As early as six months of age, children follow a shift in eye gaze or a pointing finger to an interesting object. They assume that these cues are informative and can learn from the subsequent situation, as when they hear “oh, look at that plane!” and associate the word with the object (Mundy & Gomes, 1998). This social interaction requires the integration of many simultaneous events: one must *identify* social stimuli, *interpret* information from the interaction, and *select and carry out* an appropriate response. During these interactions, one must make use of subtle visual cues directing attention to salient aspects of the environment. Once visual attention is directed, the resulting contingency (i.e., what happens as a result of the cue) needs to be recognizing and interpreted.

Social cognitive and social behavioral difficulties are characteristic of individuals with autism spectrum disorders (ASD; American Psychological Association, 2000) and researchers have proposed that difficulties in low-level visual attention, such as the ability to disengage or shift attention, may underlie social deficits in individuals with ASD (e.g., Renner, Kilinger, & Klinger, 2006; Landry, Mitchell, & Burack, 2009). While this proposal is theoretically compelling, a causal link has not been elucidated. Further complicating this claim, the existing research assessing low-level visual attention mechanisms in participants with ASD have utilized a variety of methodological techniques and have not directly compared multiple processes (e.g., disengagement, cue evaluation, inhibition, etc.), yielding mixed results. The focus of the current thesis was to assess multiple aspects of basic visual attention and social aspects of attention simultaneously, illuminating the low-level attentional processes that may contribute to the aforementioned social interactions and social development.

Visual attention in infancy. In the earliest stages of development, even before infants are able to participate in joint attention (or triadic attention in its classic definition), infants undergo dramatic changes in visual attention. Within the first three to four months, for example, infants improve their ability to scan visual stimuli (Hunnius, Geuze, van Geert, 2006) and to shift their visual attention to perceptually interesting objects in their environment (Atkinson, Hood, Wattam-Bell, & Braddick, 1992). By three months, infants require less time to process visual cues and more readily shift their attention to competing, peripheral objects (Atkinson, et al., 1992). Even at this early age, infants show improvements in attentional disengagement, shifting, and cue evaluation, indicating maturation in the neural connections supporting their attentional and executive abilities (Atkinson, et al., 1992). These improvements in visual attention allocation are hypothesized to directly precede the infant's ability to regulate affect, share attention with others, and recognize patterns in the environment (Greenspan & Shanker, 2007). Development in these areas influences the how the infant perceives the world and what aspects of the environment are perceived, including valuable information from other people in that environment.

In the social domain, infants as early as three months old are able to identify adults hands and faces as meaningful pieces of visual information, as evidenced by infants looking longer at objects that were previously touched by an adult's hand than objects touched by an inanimate object (Amano, Kezuka, & Yamamoto, 2004). They will also attend in the same direction as the eyes of a digitized adult face (Hood, Willen, & Driver, 1998), suggesting a low-level recognition that eye gaze is a meaningful, visual cue. In spite of these skills, Hood and colleagues (1998) found that three-month-old infants were less likely to follow the direction of a gaze if the face remained present on the screen; although these infants were able to follow adult gaze, they were less likely to do so when there is potent competing stimuli. This finding indicates that, despite the sophisticated evaluation and shifting abilities already on-line, the attentional disengagement system is still vulnerable to environmental pressures and continuing to develop at this age. In sum, even within the first months of life, visual attention allocation and neural maturation in brain areas supporting visual attention are beginning to shape the infant’s experience of the environment.

Later infancy and joint attention. By six months, typically developing (TD) infants begin to participate in joint attention, which can drastically enhance their social world and the environmental learning opportunities available to them. Joint attention, defined as the social and attention-based ability to share focus on an object or event in the environment with another person (Moore & Dunham, 1995), is one of the most well-studied visual attention processes in early childhood and one of the earliest markers of typical and atypical development. In typical development, children begin to follow an adult's gaze as early as six months (Kaplan & Hafner, 2006); by 9 months, they can correctly identify the target direction of a gaze if the object is located in their immediate view. By 12 months, children can determine the correct object of another's gaze, regardless of its spatial position within their visual field and by age 18-months, children can correctly identify the object of an adult's gaze even if the object is outside of their own visual field and they need to turn to search for the target object. Although 15- and 21-month old children may need additional information (such as a pointed hand or verbalization) to follow a gaze when there are many competing objects in their environment (Deák, Walden, Kaiser, & Lewis, 2008), the important point remains: even at these early developmental points, infants are using visual attention to identify social cues in the environment and, with some vulnerability to environmental pressures, can manipulate their attention based on these cues. Although joint attention is thought to be a socially-based process, the developmental trajectory of low-level visual attention described above suggests that maturation in visual attention supports, if not determines, an infant's level of joint attention participation and, reciprocally, provides opportunities to practice visual attention skills. Visual cues, in this case eye gaze and pointing, direct infants to the most important information in the environment, creating many learning opportunities and helping them to develop more control over their visual attention.

Neural correlates of joint attention support the hypothesis that joint attention development is related to and supported by neural areas recruited for more general visual attention. Functional MRI research with TD adults reveals that many of the brain regions activated during a gaze-following task overlap with activation during more general visual attention tasks, such as oculomotor control (i.e., frontal eye field, supplementary eye field, superior colliculus, and intraparietal sulcus) and non-social encoding/shifting spatial attention (intraparietal sulcus; Materna, Dicke, & Their, 2008). Only the cuneus and superior temporal sulcus regions were more activated when following gaze compared to a color-matching task that required similar visual attention shifts. The cuneus has been linked to theory of mind (Farrow, Zheng, Wilkinson, Spence, Deakin, & Tarrier, 2001) and the superior temporal sulcus has been found to be activated when passively viewing moving eyes (e.g., Pelphrey, Morris, Michelich, Allison & McCarthy, 2005). It appears that these "social" areas are activated in joint attention, in addition to the non-social, visual attention areas; in theory, these basic, non-social areas (e.g., intraparietal sulcus) may form the basis of visual attention in the environment, with socially-specific brain areas additionally recruited in joint attention (Materna, Dicke, & Their, 2008). These findings suggest that, while some brain areas may be specifically activated by the social nature of joint attention, that majority of brain activation during joint attention heavily overlaps with structures supporting non-social visual attention.

To extend this hypothesis, researchers have examined event-related potentials (ERPs) as a marker of visual attention in social and non-social paradigms. To this end, research has found that the negative component indexing attentional processes was enhanced (i.e., larger amplitude) when 9-month old infants were processing objects in a joint attention episode involving eye contact when compared to non-joint attention episodes (Striano, Reid, & Hoehl, 2006). The authors interpreted these findings to indicate that visual attention activated during joint attention episodes is more intense than in non-social interactions. Therefore, the pattern of activation may be similar in social and non-social interactions; however, the salience of joint attention may additionally assist the infant in allocating his/her limited attention capacity to important items in the environment.

The *experience-expectant* model of neural development, as reviewed by Mundy and Burnette (2005), suggests that attentional networks have evolved to take advantage of the experiences a child's environment has to offer. Using these interactions with the environment, brain develop is shaped through the strengthening of functional connections and the pruning of less useful associations. Although this model is most commonly applied to in sensory research, it is relevant to visual attention development. In the case of ASD, it can be theorized that deficits in basic, non-social (i.e., "domain-general") visual attention could negatively impact a child's ability to participate in joint attention and limit their prospects to benefit from the learning opportunities that these joint-attention engagements provide. It can be hypothesized that if "there is a robust failure of early information input into developing neural subsystems," such as the dearth of experience that could stem from decreased participation in joint attention, and a failure of pruning could result, leaving a persistent and abnormal organization of neural structure (Mundy & Burnette, 2005; pg. 658). If children with ASD have low-level visual attention deficits that impede their ability to participate in joint attention, they may not have the same opportunities to learn from their environment that a typically developing child may have. The resulting neural abnormalities will impact the child's interactions with his/her visual world throughout the lifespan.

Overall, behavioral and neurological evidence suggests that, while joint attention and gaze following are undeniably social in nature, participation in these social encounters is both shaped and supported by more general visual attention processes. The experience-expectant model highlights that participation in joint attention will shape neural development and behavioral interactions, thus impacting subsequent developmental trajectories.

Joint attention in ASD. Visual attention abnormalities are one of the first behavioral manifestations of ASD and deficits in joint attention are nearly pathognomonic. Research with young children at high risk for developing an ASD (i.e., younger siblings of children diagnosed with an ASD), provides the earliest window into attentional abnormalities in ASD. These "high risk" infants are often recruited for prospective studies of ASD; due to the heritability of ASDs, infant siblings are statistically more likely to develop an ASD than infants in the general population (up to 19 percent versus 1 percent; Ozonoff, Young, Carter, Messinger, Yirmiya, Zwaigenbaum, Bryson, et al., 2011). Sullivan and colleagues (2007) assessed high-risk infants at the ages of 14- and 24-months and found that, at 14 months, children who later received an ASD diagnosis (at three years) responded less often to joint attention bids involving eye gaze than children who would not later receive a diagnosis.

This discrepancy between groups was exaggerated at 24 months, with the ASD groups having higher rates of failing to respond to both eye gaze and pointing cues than the non-ASD group (Sullivan, Finelli, Marvin, Garrett-Mayer, Bauman, & Landa, 2007), highlighting that deficits in joint attention are unlikely to resolve. Although the researchers noted that successful participation in a response to joint attention task at 14 months cannot be used to rule out later ASD diagnoses (highlighting that children with ASD do not *lack* joint attention completely and that children may worsen in the second year of life), they did emphasize that early deficits in joint attention were not likely to remediate by 24 months in children that later received a diagnosis. Yoder, Stone, Walden, & Malesa (2009) found similar results in group of high-risk younger siblings, who were followed from 15- to 34-months of age; their results indicated that response to joint attention at the earliest time point (e.g., 15 months) predicted later social impairment and ASD diagnoses at the later assessment points (assessed in approximately 4-month increments until the age of 34 months). Also, research indicates that these joint attention deficits are unlikely to resolve as children age through preschool (Leekam, Lopez and Moore, 2000), school-age, and even into adolescence (Bean & Eigsti, 2012).

Furthermore, deficits in joint attention skills can reliably distinguish children with ASD from other children with developmental delays (e.g., global developmental delay). Research indicates that, when screening for the early detection of ASD, items relating to joint attention are key in differentiating ASD from global developmental delays and developmental language disorders (Ventola, Kleinman, Pandey, Wilson, Esser, Boorstein, Dumont-Mathieu, et al., 2007), with joint attention related items having the largest effect sizes of any measured behaviors. Investigations have also found that children with ASD, when compared to children with language delays (Barrett, Prior, & Manjiviona, 2004) and cognitive impairments (Kasari, Sigman, Mundy, & Yirmiya, 1990; Mundy, Sigman, & Kasari, 1990), engage in significantly less joint attention, indicating that visual attention abnormalities in early childhood may reflect ASD-specific processes.

Despite a lack of clarity in specific mechanisms, the importance of joint attention (and early visual attention functioning more generally) in early development is extensively documented in children with ASDs. Charman, Baron-Cohen, Swettenham, Baird, Cox, and Drew (2000) reported that, when compared to imitation and play during infancy, joint attention was the only behavior that was longitudinally associated with theory of mind abilities at 44 months. Joint attention is thought to directly influence children's language acquisition, as well, with research indicating that the visual attention and object references made by mothers within joint attention interactions are positively correlated with children's subsequent lexical development (Tomasello & Farrar, 1986). Mundy and Gomes (1998) extended this work, finding that individual differences in language use within the first 2 years of life may be distinctly related to initiation of and response to joint attention development. Furthermore, the predictive influence of joint attention for language growth cannot be explained by global developmental characteristics, such as IQ (Siller & Sigman, 2008). Additionally, joint attention engagement is directly related to children's social cognitive developmental, such as fluency with multi-person conversations (Barton & Tomasello, 1991) and self-regulatory behaviors, including distraction, comfort-seeking, self-soothing (Raver, 1996).

Despite lower rates of responding to joint attention overall, a recent study with 12- to 23-month old siblings has also shown that response to joint attention may partially depend on the visual cue that is provided to initiate the interaction. "Moderately redundant" cues (e.g., eye gaze and verbalization) were shown to be the most difficult for ASD siblings, while more simplified cues (e.g., adding a pointed finger) allow for ASD siblings to perform similarly to TD siblings (Presmanes, Walden, Stone, & Yoder, 2007). This finding suggests that, while broadly defined joint attention deficits are characteristic of the social impairments found in ASDs and are one of the earliest predictors of later deficits, the visual attention processes underlying joint attention are multifaceted. By modifying visual cues, these researchers were able to "improve" joint attention participation in their at-risk participants. This finding emphasizes that children with ASD do not *lack* the ability to participate in joint attention. Rather, they have weaknesses in the attentional skills that are required in order to participate in a typical manner. A better understanding of these mechanisms may shed light into the nature of this attentional abnormality and potential intervention options to change the course of development for these children.

In sum, research with joint attention, one of the earliest manifestations of visual attention abnormalities in ASD, can be summarized in three main points. First, joint attention deficits are nearly pathognomonic to ASD, providing a key differentiation between ASDs and other developmental disabilities. Second, these early visual attention abnormalities (i.e., reduced triadic attention participation) directly influence the development of higher-order skills, such as social functioning and language. Third, research has hinted that modifying visual cues and environmental characteristics may alter the performance of high-risk infants. This third point suggests that the social and attentional process of "joint attention" could be broken down into smaller, lower-level processes (as evidenced by experiments using socially-relevant stimuli). Assessing these more basic processes could shed light on (1) what aspects of visual attention make it more difficult for children with ASD to participate in joint attention and (2) how these low-level mechanisms could be addressed to provide this high-risk population with additional learning opportunities and could alter the course of their social development.

Evidence for abnormalities in visual attention using social stimuli with older children. Many studies have explored visual attention in ASD with "ecologically valid" paradigms, such as interactions with caregivers or viewing photos of real faces. In reference to visual orienting, for example, research indicates that children with ASD demonstrate a social-specific orienting deficit. This deficit was demonstrated by decreased visual attention to and attempts to engage a person, but not objects, when compared to children with TD children or Down Syndrome (Adamson, Deckner, & Bakeman, 2010). In contrast, some evidence points to a decreased tendency to orient to both social and nonsocial stimuli (e.g., another's gaze and a jack-in-the-box; Dawson, Meltzoff, Osterling, Rinaldi, & Brown, 1998).

In addition to general social orienting, studies evaluating the *utilization* of visual, social cues have reported mixed results. The literature is fairly consistent in documenting abnormalities in the visual scanning of faces in ASD. Most often, participants with ASD are observed to spend less time visually fixating on eyes (and more time visually inspecting mouths, bodies and objects) than their TD counterparts (Klin, Jones, Schultz, Volkmar, & Cohen, 2002). It should be noted that results are less definitive for participants with comorbid language impairments (Norbury, Brock, Cragg, Einav, Griffiths, & Nation, 2009). Also, research varies in the predictive value of eye-scanning abnormalities for social impairments, ranging from evidence for eye-movement patterns being strongly predictive (e.g., Klin et al., 2002) or not at all predictive (e.g., Norbury et al., 2009) of social competence. Results pertaining to the "use" of eyes as a visual cue (i.e., reflexively orienting to changes in eye gaze) in children with ASD are also diverse, with evidence for intact automatic cueing (Chawarska, Klin, & Volkmar, 2003; Swettenham, Condie, Campbell, Milne, & Coleman, 2003) and reduced spontaneous gaze following (Leekam, Baron-Cohen, Perrett, Milders, & Brown, 1997) compared to children with TD.

At the level of brain functioning, fMRI and ERP studies have reported social-specific abnormalities in individuals with ASD, compared to TD participants. These findings highlight impairments in face-related cortex (i.e., fusiform gyrus) and in the temporal processing of faces, but not objects (Scherf, Luna, Minshew, & Behrmann, 2010; McPartland, Dawson, Webb, Panagiotides, & Carver, 2005). Yet, other studies have found abnormal ERP responses for both faces and objects in children with ASD compared to TD and developmentally-delayed children (Webb, Dawson, Bernier, & Panagiotides, 2006), calling into question the social specificity of visual scanning abnormalities in ASD.

Finally, results describing disengagement and attention shifting for visual, social stimuli is also mixed. In some instances, “sticky attention” has been found (as measured by frequency of shifts when looking at a caregiver’s face) in six-month old infants at high risk for ASD (Ibanez, Messinger, Newell, Lambert, & Sheskin, 2008). Fewer attentional shifts between people and objects than TD or developmentally-delayed infants at 20-months of age are also documented (Swettenham, Baron-Cohen, Charman, Cox, Baird, Drew, Rees, & Wheelwright, 1998). Although not using social stimuli (i.e., blinking lights), a study with 150 infant siblings showed that slower disengagement from a central visual cue to a peripheral visual stimulus from ages six to 12 months was the best predictor of an ASD diagnosis at 24 months (Zwaigenbaum, Bryson, Rogers, Roberts, Brian, & Szatmari, 2005). Though this predictor was highly sensitive, the authors were unable to mechanistically link attentional disengagement to symptomatology. In contrast, other studies have found easier disengagement from social stimuli (i.e., photos of faces) in individuals with ASD (children: Chawarska, Volkmar, & Klin, 2010; adults: Vlamings, Stauder, van Son, & Mottron, 2005). Chawarska et al. (2010), for example, found that children with ASD were significantly faster to shift their gaze from the cue picture to the target location than both TD and developmentally-delayed children, when using static images of a face with directive eye gazes and measuring saccadic reaction time (RT). Chawarska and colleagues suggested that children with ASD were processing the cues more superficially and with less initial engagement, thus making them faster to disengage.

Overall, research assessing visual attention properties for social stimuli in individuals with ASD has utilized a variety of techniques (e.g., experimental paradigms and environmental observations), stimuli (e.g., static and dynamic images, real faces and cartoons, etc.), and ages of participants (ranging from infants to adults), making direct comparisons and interpretations of general patterns difficult. Whether these studies are reporting deficits with disengagement (i.e., “sticky” attention) or with orienting to and evaluating social cues, these findings suggest that visual attention abnormalities in this population may extend beyond the social realm. Although this prior research indicates that children with ASD interact differently with socially relevant, visual information, it has not specifically explored the causal association between abnormalities in visual attention and social functioning and, therefore, the mechanisms linking these two processes remain unclear.

Theories of visual, social attention abnormalities in ASD. As a launching point for a low-level, visual attention approach to understanding the social abnormalities in ASD, several theories have been developed to explain early deficits in joint attention and social functioning. Research to date has pointed to three hypotheses regarding the link between visual attention and social functioning in ASD. These accounts attempt to explain *why* children with ASD struggle to appreciate social visual cues and the resulting contingencies. The first theory implicates *decreased interpersonal relatedness*; this affective explanation suggests that children with ASD have difficulty regulating their emotional responses during a joint attention interaction and, therefore experience "jointness" as distressing and aversive (Leekam & Moore, 2001). The second theory suggests a *deficit in theory of mind and decreased awareness of the significance of social cues*; social impairments in this model stem from a cognitive deficit in the ability to represent another person's intention and, therefore, an inability to understand the cue (e.g., eye gaze) as meaningful (Leekam & Moore, 2001). While these theories have some theoretical and empirical support, they are both social in nature and cannot account for domain-general impairments in visual attention and changes in performance with changes in cue presentation, and as such, could not be the sole explanation for concurrent deficits.

A third theory, and the focus of this discussion, proposes that differences in domain-general attention are the link between visual attention abnormalities and social functioning in ASD (i.e., *multiple processes model*). Under this account, changes in the underlying mechanisms of flexibility, disengagement, or cue evaluation/utilization prevent children with ASD from typical participation in social cuing interactions. In the joint attention example, this model suggests that children with ASD have difficulty disengaging from their current focus of attention to attend to the social cue (e.g., pointing). If they are able to disengage, there may be differences in the neural mechanisms involved in evaluation, thus making children with ASD less efficient interpreters of the cue's meaning. In theory, children with ASD are less likely to orient to a cue that they do not assume to be predictive (Gernsbacher, Stevenson, Khandakar, & Goldsmith, 2008). This inefficiency makes children with ASD less likely to learn the contingency between the cue and the target. Theoretically, children might develop top-down compensatory strategies, but continue to exhibit low-level abnormalities suggestive of visual attention "inefficiencies" on tasks tapping bottom-up approaches to attention and social action (Leekam & Moore, 2001; Nation & Penny, 2008).

Evidence for domain-general attentional functioning in ASD. In order to pursue domain-general attentional processes underlying the link between visual attention abnormalities and social competence, a review of the visual attention literature in ASDs was conducted to identify potential mechanisms (or "visual attention inefficiencies"). Briefly, domain-general attention paradigms with participants with ASD generally support intact sustained and selective attention (Allen & Courchesne, 2001; Ames & Fletcher-Watson, 2010; Casey, Gordon, Mannheim, & Rumsey, 1993; Garretson, Fein, & Waterhouse, 1990; Sanders, Johnson, Garavan, Gill, & Gallagher, 2008). Associative learning is also intact (Bhat, Galloway, & Landa, 2010), suggesting that children with ASD can learn contingencies from the environment if their attention is appropriately allocated. The most commonly documented attentional impairments in this population, when assessing attention using non-social stimuli, are in the realm of both voluntary and automatic spatial attention (Akshoomoff, 2005); these impairments are most often seen in disengaging, shifting, and rapidly re-orienting attention (Allen & Courchesne, 2001; Ames & Fletcher-Watson, 2010; Casey et al., 1993; Courchesne, Townsend, Akshoomoff, Saitoh, Yeung-Courchesne, Lincoln, James, Haas, Schreibman, & Lau, 1994; Sanders et al., 2008). The documentation of these deficits has stemmed from a variety of methods, stimuli, and study samples, making comparisons across attention processes difficult. However, similar set shifting issues documented in the executive functioning literature, as well as neurophysiological evidence, suggests that shifting impairments in this population are the result of cognitive neural networks (e.g., parietal cortex) and not pure motor dysfunction or eye movement deficits (Eigsti, 2011; Courchesne et al. 1994; Luna, Minshew, Garver, Lazar, Thulborn, Eddy, & Sweeney, 2002). The diffuse and functional neuroanatomical abnormalities characteristic of ASDs, rather than a localized, focal deficit (Eigsti & Shapiro, 2003), further suggest these attentional abnormalities may be both the sequellea of and contributing mechanisms to abnormal brain development in this population. The better understanding there is of these mechanisms and the lower-level process that may underlie the aforementioned executive and attentional findings, the more intervention tools there will be to target these processes directly and earlier in development.

Posner's theory of attention. The most well-known task designed to assess the aforementioned low-level attentional mechanisms (i.e., disengaging, shifting, re-orienting, and cue evaluation) is based on Posner's (1980) theory of attention. Posner's multifunction system focused primarily on visual attention and consisted of three anatomically connected, but independent networks: *alerting, orienting*, and *executive control*. The alerting network allows a person to maintain an alert state; the orienting network is defined as the ability to change the priority of a stimulus or a location in the visual field; the executive network is the ability to flexibly reprioritize attention based on changes in one's goals or environment. In Posner's attention-cuing paradigm, based on these networks, participants respond as quickly as possible to a visual target that is presented to the left or the right of a central fixation cross. There are three trial types: neutral, valid, and invalid. On neutral trials, which establish a reaction time (RT) baseline, the target appears to the right or left of the fixation cross with no warning. In valid trials (80% of the cued trials), an arrow appears in the center of the screen and predicts the target's location; on invalid trials (20% of cued trials), the arrow incorrectly directs the participant's attention to the opposite side of the screen. RT is recorded when the participant selects the target. The arrow cues orient participants to the physical location of the target; the conflict between invalid cues and the subsequent target location must be resolved using executive processing. Posner found that the cost (increased RT) associated with invalid trials, known as the *validity effect*, did not depend on eye movements; therefore, attention orienting is not synonymous with eye movements.

Since Posner's seminal 1980 article, several researchers have investigated versions of his paradigm utilizing behavioral and neuroimaging techniques to assess the authenticity of his network theory. Fan, Gu, Guise, Liu, Fossella et al. (2009), for example, modified Posner's paradigm to examine the independence and possible interactions of his three networks. Fan and colleagues added a "double cue" which serves to alert the participant to the impending target, but does not provide any spatial orienting. In addition to the four exogenous (i.e., peripheral) cues: no cue, double cues, spatially-valid cues (75%), spatially-invalid cues (25%), Fan et al. (2009) created congruent and incongruent targets. The participant was asked to determine the direction of the center arrow, while the flanking arrows in the target were pointing in the same direction (congruent) or the opposite direction (incongruent). The target stimuli appeared above or below the fixation point.

Fan et al. (2009) found that, with TD adults, the data from their aforementioned design was in support of Posner's three network theory. First, they observed that the alerting network (i.e., the difference in RT between no cue and the double cue) improved overall RT but exerted a negative influence on the executive network (i.e., incongruent targets). Second, they found that the validity of the cue interacted with the congruency of the target. The authors hypothesized that both of these findings might stem from competition for the anterior cingulate gyrus. Finally, the authors noted that orienting effects (i.e., the facilitation of valid cues and the cost of invalid cues) suggested that participants consciously or unconsciously learned the cue-target contingencies, and used this information to improve performance.

This combination of independence and interaction among three attentional networks is supported by electrophysiological and neuroimaging studies. In an ERP study, Neuhaus, Urbanek, Opgen-Rhein, Hahn, Ta, et al. (2010) found enhancement of a target N1 with both alerting and orienting effects. Alerting enhanced posterior N1 over the parietal lobe, while orienting induced early N1 enhancement over the occipital lobe, suggesting a larger visual component in orienting than in alerting. Also, they noted a modulation of the P3 amplitude, specifically a frontal increment and parietal decrement, during response inhibition (i.e., executive network).

There is an extensive and consistent literature of neuroimaging findings in support of these networks as well, from both typically developing and clinical adult populations as reviewed by Fan et al. (2009). In brief, the alerting network is associated with norepinephrine systems arising in the thalamic midbrain region and extending to frontal and parietal regions. The orienting network is supported by superior and inferior parietal lobules (disengaging), with connections to the frontal eye fields (moving) and subcortical regions (engaging). This orienting network appears to be modulated by the basal forebrain cholinergic system. Finally, the executive control network is supported by the anterior cingulate and lateral prefrontal cortices, which are supplied by the ventral tegmental dopamine system (Fan et al., 2009). Overall, behavioral, neuroimaging, and electrophsyisoloical studies with adults support Posner's (1980) theory of three independent, but connected attentional networks.

Evidence for attentional networks in children using Posner's paradigm. The aforementioned research utilizing versions of Posner's (1980) was all conducted with adults. Evidence from children and adolescents can provide insights into the developmental trajectory of these abilities.

To investigate this question, Rueda, Fan, McCandliss, Halparin, Gruber et al. (2004) conducted a series of three experiments with a child version of the attentional networks task described by Fan and colleagues (2009). The experimenters utilized a similar exogenous cue system (i.e., no cue, double cue, and spatially-valid cues) and changed the target arrows into cartoon fish. The children were given visual and auditory feedback when they responded correctly. Rueda et al. (2004) compared TD children (10 years old) and adults on both the child and adult versions of the task. The evidence indicated that the three attentional networks are (behaviorally) operating in the same fashion in children as they do in adults. The only difference between the two groups when compared directly was in overall RT, with adults reacting faster than children. An experiment with a larger group of children (ages six- to eight-years) confirmed a lack of correlations between the network effects, consistent with the findings in typical adults. These data indicate that the child version of the task taps into three statistically independent functions much like the adult version is assumed to do. When four groups of children, ages six-, seven-, eight-, and nine-years, were compared the results again suggested that children become faster and more accurate with age; however, there were no significant, steady changes or improvements with age for the three networks. Rather, the evidence indicated that the alerting and orienting network are stable beginning with the youngest children (i.e., six-year-olds), while the executive network improved between the ages of six and seven years, but was stable after that point.

Overall, this series of experiments proposed that Posner's three networks of attention function in school-age children in a similar way compared to adults. Orienting and alerting are assumed to be stable prior to age six. Improvements in the executive network were noted to reach a point of stability between age seven and adulthood. Increases in RT and accuracy steadily improved with age. Of note, however, Rueda and colleagues did not use any invalid spatial cues; therefore the disengagement and shifting load in these tasks was relatively low. In sum, it appears that Posner's paradigm is theoretically appropriate for children as young as seven years old.

The attentional networks in atypically developing children. Several pediatric populations have been identified as having atypical attentional abilities and have completed Posner-style paradigms with informative and clinically relevant results. This paradigm has proved useful in a variety of disparate clinical populations, such as preterm children, children with developmental coordination disorder (DCD), and children with attention-deficit/hyperactivity disorder (ADHD). In preterm children, for example, past studies implicate difficulty with executive functions, such as inhibition and shifting, but not impairments in sustained and/or selective attention. In an experiment with preterm children (mean chronological age = 5.8 years), Pizzo and colleagues (2010) compared the performance of children with a gestational age of 25 to 32 weeks (i.e., preterm) to children with full-term births on an attentional network task. The authors found that the full-term children were faster and more accurate and, consistent with prior research, there the groups differed for the executive network only. The preterm children had more difficulty resisting the distracter interference. Interestingly, the authors found that the executive control and orienting networks were significantly correlated in the preterm group only; this finding sheds light on previous findings suggesting both inhibition and shifting difficulties in these children (Pizzo, Urben, Van der Linden, Borradori-Tolsa, Freschi, et al., 2010). These results suggested less differentiation between those two networks in preterm children, indicative of less automatic orienting and the need for more cognitive control to disengage, shift and re-engage.

Behavioral evidence from children with developmental coordination disorder (DCD) demonstrates difficulties in visuospatial information processing specific to endogenous orienting and poor motor performance (Tsai, Pan, Cherng, Hsu, & Chiu, 2009). DCD is a diagnosis made on the basis of poor motor proficiency, in the absence of an identifiable neurological cause; these deficits are theorized to reflect right hemispheric insufficiencies and/or dysfunction of the corpus collosum, but empirical evidence for neurological dysfunction is limited (Tsai et al., 2009). When compared to TD children, children with DCD (mean age = 9.5 years) demonstrated increased overall RT and greater cost with invalid cues, suggesting they are slower to disengage from the inaccurate spatial location once they are primed. Importantly, the children with DCD did not demonstrate an increase in error rates. Furthermore, ERP evidence with the same group of children suggested that the children with DCD were slower with target identification and demonstrated reduced anticipatory processes, as measured by the contingent negative variation. Interestingly, however, they showed the same overall distribution of activity as TD children. Overall, both the Posner paradigm and ERP evidence suggest that children with DCD are performing the task in the same manner, but are both cognitively and motorically slower.

In contrast, children with ADHD show deficits in sustained attention and impulsivity in conditions of conflict (Adólfsdóttir, Sørensen, & Lundervold, 2008). Adólfsdóttir et al. (2008) found that children with ADHD (mean age = 10.3 years), when compared to TD children and children with other psychiatric diagnoses, did not demonstrate any deficits on the identified attentional networks. Rather, the group with ADHD was found to demonstrate significantly more errors and wrong-sided responses. Also, the ADHD group was the only group who demonstrated a significant correlation between IQ scores and accuracy, suggesting a similar process affecting both performance scores. Other studies have confirmed these findings, suggesting that children with ADHD tend to be slower across all conditions, related to inattentiveness, but show a similar validity effect as TD children (Alvarez & Freides, 2004). In contrast, another review of the literature on the performance of children with ADHD in Posner-like tasks suggested some evidence for an increased validity effect, reflecting their weaker executive control in overcoming incongruent trials (Mullane, Corkum, Klein, & McLaughlin, 2009).

In sum, these findings in support of increased RT and number of errors (and, potentially, an increase in validity cost related to issues of cognitive control and inattention) in ADHD samples are consistent with behavioral and neurobiological evidence of the neural deficits in this population, namely dysfunction in prefrontal cortex and connected regions (Kim, Lee, Shin, Cho, & Lee, 2002; Faraone & Bierderman, 1998). Importantly, children with ADHD, despite social rejection and socially-inappropriate behavior related to their inattentiveness and impulsivity, do not experience the early deficits in joint attention previous described in ASDs (Nijmeijer, Minderaa, Buitelaar, Mulligan, Hartman, & Hoekstra, 2008; Hoza, Mrug, Gerdes, Hinshaw, Bukowski, Gold, et al., 2005). Therefore, children with ADHD are an ideal comparison group for children with ASD, to assess the attentional dysfunction that could be attributable to pure inattention, without comorbid social attention abnormalities.

Overall, the attentional network task appears to be a behavioral measure of attention that is (a) supported by behavioral and neuroimaging studies in adults, (b) appropriate and valid in pediatric populations, and (c) sensitive and specific enough to demonstrate unique patterns for disparate types of attentional difficulties in atypically developing children. This evidence points to this paradigm as a simple, relatively quick means of acquiring data about low-level, fundamental attentional mechanisms. Data from individuals with ASD using this attentional paradigm would be beneficial; despite their documented attentional abnormalities, the relation of attentional processes to other mechanisms and skills has not been investigated in a within-subjects manner, which would provide the link between low-level attentional processes and social development.

Posner-inspired tasks with ASD populations. Despite seemingly intuitive hypotheses based on early observational and socially-based research, the evidence for attentional abnormalities using Posner-style paradigms with individuals with ASD is extremely varied.

Cue evaluation in ASD. In Posner's paradigm, valid and invalid cues are used to assess the participant's ability to benefit from (domain-general) cue predictiveness (i.e., process the meaning of the cue). In theory, if participants are less impacted by the invalid cue (as measured by RT), one can assume that they are not "processing" the cue's predictive value and, therefore, are less likely to direct attention to the incorrect location. As previously mentioned, research assessing the predictive value of eye gaze in children with ASD has yielded mixed results; some evidence points to intact automatic cueing (Chawarska, Klin, & Volkmar, 2003; Swettenham, Condie, Campbell, Milne, & Coleman, 2003), while others report reduced spontaneous gaze following (Leekam, Baron-Cohen, Perrett, Milders, & Brown, 1997) compared to children with TD. A deficit in using eye gaze as a predictive cue has been cited as a potential mechanism in the observed joint attention and social deficits characteristic of this population.

When assessing the validity effect with ASD participants, the findings are mixed. One body of evidence suggests intact cueing (i.e., statistically similar validity effects for arrow cues) in individuals with ASD and typical development (Renner, Klinger & Klinger, 2006; Landry, Mitchell, & Burrak, 2009; Todd, Mills, Wilson, Plumb, & Mon-Williams, 2009). Renner and colleagues (2006) found no group differences between their ASD and TD participants (ages 7- to 17-years) in the speed of orienting to the cued location and in the validity effect. However, this study utilized camera-recorded eye movements as a marker of attention shifts, therefore limiting the precision with which they could detect group differences in attention (compared to measuring response time or gaze shifts in milliseconds). Landry et al. (2009) reported similar results comparing children with ASD and TD (mean age of 11 years); utilizing central arrows of varying presentation lengths after varying latencies between cue and target presentation, and using reaction time (through a button press) as the dependant variable, these researchers found that their ASD participants demonstrated a similar validity effect as their TD participants, even at the shortest cue duration. They concluded that even a brief cue presentation (100 ms) was long enough for their ASD participants to adequately process the cue information.

Additionally, studies also report statistically similar cueing effects for static cartoons of eye gaze (Kuhn, Benson, Fletcher-Watson, Kovshoff, McCormick, Kirkby, & Leekam, 2010; Senju, Tojo, Dairoku, & Hasegawa, 2004), as measured by saccade latency in adults and behavioral reaction in children with ASD and TD, respectively. While these findings are promising, Kuhn and colleagues (2010) utilized line drawings of a face, while Senju et al. (2004) used a still image of a face, making direct comparisons between studies and between arrows and faces (which are not matched for visual complexity) difficult. This methodological point is discussed in more detail later.

Though these studies report no group differences in validity effects in ASD, indicating intact cue interpretation, several hint at differences in cue *evaluation* and the ability to use cues to inform behavior. Landry, et al. (2009) found that children with ASD benefited from an arrow cue as much as their typically developing counterparts (as evidenced by a similar validity effect at the shortest cue interval, 100 milliseconds).

However, cues were not predictive of the target location (50% valid). When the interval between cue and target was increased to 400 ms, children with TD had reduced validity effects, indicating that they began to disregard the arrow cue. In contrast, children with ASD had *increased* validity effects at the longer intervals. These findings indicate that children with ASD failed to learn that the cues were uninformative, or were less able to use this information in attention orienting. The authors concluded that, while their participants with ASD were able to process cues effectively, they were slower to execute an attentional response when cognitive control was needed. Also documenting deficits in cue evaluation, Wainwright-Sharp & Bryson (1993), reported *smaller* validity effects in individuals with ASD when cues were presented for 100 ms, but significantly *greater* validity effects for cues at 800 ms. The authors suggested that young adults with ASD may have (1) a deficit in interpreting arrow cues as quickly as their TD peers and, if they are given enough information about the cues meaning, (2) more difficulty overriding the invalid cue once their attention is allocated. Taken together, findings suggest that individuals with ASD process cues more superficially, are less able to predict the target location, and struggle more when needing to implement cognitive control to reallocate attention after an invalid cue.

In summary, studies of the evaluation and interpretation of visual cues in ASD have had mixed results. Some studies suggest intact abilities to interpret cues, while others suggest superficial cue evaluation and an inability to modify behavior accordingly. If individuals with ASD have deficits in *cue evaluation*, their social difficulties may reflect deficits in interpreting cues, like pointing.

Disengagement in ASD. Another proposed mechanism for social, visual attention deficits in ASD is the presences of "sticky attention," or the inability to disengage attention effectively (e.g., Ibanez et al., 2008; Zwaigenbaum et al., 2005). In the traditional Posner paradigm, the cue disappears before the target is presented. To investigate sticky attention, Landry and Bryson (2004) reported that 6-year-old children with ASD were slower than participants with TD or Downs Syndrome to disengage from a blinking light that continued to blink when the target (i.e., a second light) was presented. The ASD group also had the highest rate of trials during which they failed to disengage from the cue at all (as measured by camera-recorded eye movements), which were included in their reaction time analyses. Another study utilizing non-predictive central cues with infant siblings of children with ASD (8- to 12-months old) also reported slower looks to peripheral targets when the cue remained on screen (Elsabbagh, Volein, Holmboe, Tucker, Csibra, Baron-Cohen, et al., 2009). These findings suggested that sticky attention in ASD could contribute to social impairments and atypical development.

Data from studies with predictive cues and older participants, however, have been inconsistent. In a study of children with ASD ages 9 to 15 years, participants completed a variant of the Posner task, in which the central cue remained onscreen when the target appeared (i.e., a "competition" manipulation). Findings suggested no deficits in the ASD group (Todd, et al., 2009). Furthermore, in a study of children with ASD aged 10-years and in a study with adult participants, the ASD group had *less* of a competition cost (Van der Geest, Kemner, Camfferman, Verbaten, & van Engeland; 2001; Kawakubo, Maekawa, Itoh, Hasimoto, & Iwanami, 2004); both studies measured responses by recording express saccades after non-directional cues. These findings suggest that decreased attentional engagement with cues rather than a disengagement issue could be associated with social impairment.

Clearly, results from many studies suggest meaningful differences in low-level attentional processing in ASD. One open question is whether cue *evaluation* (that is, how information from visual cues is interpreted and used to inform behavior) or cue *disengagement* (that is, how quickly one can shift attention from the cue to the target) predicts ASD symptomalogy and social behavior. At present, existing findings are limited by variability in age of participants (ranging from infants to adults), methodological differences in data analysis (e.g., some studies do not remove outliers or non-responses), and by stimuli (faces and arrows that differ in luminosity or visual complexity). Also, many studies make hypotheses about alternative mechanism influencing their results (e.g., response inhibition/cognitive control, visual field differences, etc.), without directly measuring those constructs. Finally, many studies use eye movements as the dependent measure of attention shifting (via analyzing frames from a video camera), or rely on a behavioral response, but no study has reported both. Because attention shifts can occur with or without eye movements (Posner, 1980), eye movements and behavioral responses may be distinct ways of orienting in a visual world.

Additional attentional mechanisms. To address these concerns regarding alternative mechanisms, the current study explored three more processes: (1) response build-up, (2) social salience of the cue, and (3) laterality of the target presentation. To our knowledge, these constructs have not been consistently evaluated using Posner tasks; therefore, the following literature review focuses primarily on results stemming from alternative paradigms and makes hypotheses about how these mechanisms may influence performance on Posner-style tasks.

Response build-up (inhibition). Cognitive control, or response inhibition, is an area of extensive research, both in typical and atypical development. The predictive trajectory of cognitive control begins as early as preschool (Eigsti, Zayas, Mischel, Shoda, Ayduk, Dadlani, et al., 2006) and continues to mature and develop throughout adolescence (Luna, Padmanabhan, & O'Hearn, 2010). Although children with ASD may not demonstrate neurodevelopmentally-typical, age-related improvements in cognitive control (Solomon, Ozonoff, Cummings, & Carter, 2008), they are typically less impaired in response inhibition than peers with ADHD (Happé, Booth, Charlton, & Hughes, 2006). In the Posner paradigm, trial-by-trial learning has been documented via ERP recordings in TD adults, suggesting that the predictive value of the cue builds based on the preceding trial (Gómez, Flores, Digiacomo, & Vázquez-Marrufo, 2009). Although not directly studied to our knowledge, the use of a carefully controlled measure of response inhibition in Posner-style task would allow for the direct assessment of cognitive control in the context of cue evaluation and disengagement and would, therefore, shed light on possible data interpretations.

Social salience of the cues. The comparison of social (e.g., faces) and non-social (e.g., arrows) visual information have extensive literature basis in studies with ASD populations. Studies with TD preschool children and adults report that rates of reflexive orienting are similar for arrows and line drawings of eye gaze (Ristic, Friesen, & Kingston, 2002), even if the cues are non-predictive. When college students were asked specifically to ignore a central cue, arrows and a cartoon's eye gaze produced similar rates of automatic saccades (Kuhn & Kingstone, 2009). Although some studies suggest a stronger effect automatic cueing effect for eye gaze in TD adults (Friesen, Ristic, & Kingstone, 2004), the difference in visual properties (e.g., complexity) between the two stimuli makes direct comparisons difficult.

In a study with adults with ASDs, in which automatic cueing was assessed for arrows and eye gaze cartoons "distractors" prior to the onset of a predictive color cue, there was no difference between the adults with and without ASD in automatic cueing for eyes or arrows (Kuhn, Benson, Fletcher-Watson, Kovshoff, McComick, et al., 2010). However, both groups had longer response latencies with arrows.

When assessing school-aged children with and without ASDs, both predictive arrows and a still image of a face created a facilitation effect (i.e., faster RT when pressing a button; Vaidya, Foss-Feig, Shook, Kaplan, Kenworthy, & Gaillard, 2011); however, the validity effect for arrows was larger in the ASD group than the TD group.

Although these findings provide valuable information about the processing of social and nonsocial visual information, in order to evaluate these findings with regard to low-level attentional mechanisms, the visual properties must be matched to rule out a visual attention or visual processing explanation prior to the higher-order processing of "social salience."

Laterality and visual-field differences. Reaction time (RT) to stimuli presented in one of the two visual fields (i.e., right or left) has long been used as a marker of neural laterality and the efficiency of neural functioning in the contralateral hemisphere. In one well-documented finding, the *right visual field advantage*, participants have faster RT for language-based information presented in the right visual field. This has been taken to suggest that the left hemisphere is more efficient in processing language-based stimuli (Nicholls & Wood, 1998). Kinsbourne (1970) described a more general process of "perceptual asymmetries," suggesting that differences in RT for the two visual fields are related to a dynamic process distributing spatial attention. Kinsbourne suggests that the RT differences are a marker of an "activational imbalance" between the hemispheres, with the more activated hemisphere deploying attention to the contralateral hemispace. TD, right-handed college students, when asked to respond with right or left hand to auditory tones, demonstrated an interaction between the hand that was used to respond and validity: as a group, they were significantly slower for invalid cues when responding with their left hand (Bestelmeyer & Carey, 2004). The authors used these findings to suggest inefficiencies in the right hemisphere for correcting movement errors and/or assessing movements in progress; this explanation is consistent with evidence suggesting left hemispheric dominance for supporting response selection and inhibition (Bestelmeyer & Carey, 2004) and faster RT for visually-presented, right-sided targets (Poy, Eixarch, Ávila, 2004).

Visual field differences can be especially relevant in atypical development. Vlamings et al. (2005), for instance, found that their adult TD group experienced a validity effect for arrow cues bilaterally, while the validity effect for eye gaze cues (i.e., a static image of a face with laterally gazing eyes) was only present for targets in the right visual field. An adult ASD group, in contrast, demonstrated validity effects for eye gaze cues bilaterally; however, arrow cues only created a validity effect in the right visual field. The TD and ASD groups demonstrated complementary patterns of facilitation.

In another study of laterality and visual field differences with children with ASD, Stauder, Bosch, and Nuij (2011) used the stimuli presented in Vlamings et al. (2005) and also found validity effect differences for face and arrow cues. Stauder and colleagues noted that their TD group showed validity effects for arrow cues bilaterally, while eye gaze cues only created a validity effect in the right visual field; the ASD group showed a validity effect for arrows in the right visual field and for eye gaze in the left visual field only. These findings suggest that, while general cueing may be intact and functional for the ASD participants, subtle differences in laterality may affect processing efficiency and could, in theory, contribute to their lessened involvement in joint attention.

In reference to RT, Rinehart, Bradshaw, Brereton, and Tonge (2002) used a visual choice RT paradigm found that their high functioning autism group (HFA; mean age of 9 years) demonstrated more errors and slower RT when their attention was moving rightward than leftward. Neither a TD nor an Asperger's Syndrome group demonstrated a directional effect. These authors also used a peripheral cueing paradigm (with no validity manipulation) to demonstrate that their HFA group was less likely to anticipate targets when they were presented in the right visual field versus the left visual field; this pattern did not emerge for either of their comparison groups (Rinehart, Bradshaw, Brereton, & Tonge, 2002). These findings suggest left hemisphere inefficiencies in the HFA group. The Asperger's group in this study appeared to be older (12.8 versus 9.1 years old) and scored higher on the IQ measure (101.5 versus 93.3), which could be contributing to differences in performance, especially given that executive functioning differences may underlie these findings.

Finally, eye movement studies have indicated lateralized differences in visual field processing, which may inform hypotheses about the connection between low-level attentional mechanisms and higher-order functioning. Pursuit eye movements, for example, have been tested to assess for visual abnormalities in participants with ASD. In a study of young adults with ASD and TD, researchers have identified bilateral deficits in eye movements that are based on memory for target velocity, predictions about target location, and feedback from performance in their ASD participants. In contrast, eye movements based on sensory analysis, were abnormal in the right visual field only (Takarae, Minshew, Luna, Krisky, & Sweeney, 2004). These eye movement deficits, which reflected basic motor performance, suggested a deficit in transferring information from the sensory to motor systems when information is presented in the right visual field only. In a study with ASD participants ranging from 8 to 56 years old, faster rightward responses throughout the trials and a higher proportion of rightward (versus leftward) anticipatory saccades were found in the ASD group, but not the TD group (D'Cruz, Mosconi, Steele, Rubin, Luna, Minshew, & Sweeney, 2009). There were no group differences reported on visually-guided saccade tasks, only trials when predictions of the target location were required.

Pursuit eye movements in TD populations are thought to be related to neural activity in the frontal eye field, supplementary eye field, intraparietal sulcus, precuneus, and anterior/posterior cingulated cortex (Berman, Colby, Genovese, Voyvodic, Luna, Thulborn, & Sweeney, 1999), many of which overlap with activations noted during attentional tasks. Takarae, Minshew, Luna and Sweeney (2007) found atypical activation in adults with ASD, with fMRI evidence indicating reduced activation in sensorimotor areas and increased blood flow in activation and execution areas. The authors interpreted their findings to suggest that the ASD group, despite no difference in their response latency, may be relying on brain areas that are normally specialized for other functions, making their neural functioning less efficient. In sum, findings indicate that individuals with ASD demonstrate visual tracking inefficiencies and, in particular, right visual-field processing abnormalities.

In ADHD, eye movement studies suggest an inability to suppress unwanted eye movements and to control voluntary saccades, consistent with behavioral evidence supporting deficits in inhibition (Rommelse, Van der Stigchel, & Sergeant, 2008). A review noted that eye movement studies in ASD are inconsistent; however, multiple studies have demonstrated frequent antisaccade errors (a marker of response inhibition), which rely on frontal structures, and smooth pursuit abnormalities, which are related to subcortical areas in children with ASDs. These findings indicate, consistent with behavioral evidence, that individuals with ASDs are impacted by inattention; however, it is likely that the inattention that affects social development in ASD is multifaceted and neurologically dispersed compared to the inattention characteristic of ADHD.

Summary. ASDs are characterized by social cognitive and social behavioral deficits. Social participation requires the processing and utilization of visual information and infants as young as three months begin to use visual attention to shape their experiences. Under the *experience-expectant* model, these early experiences in turn shape neurological development, setting children on a typical or atypical developmental trajectory. In the case of ASD, early manifestations of atypical visual, social attention (i.e., joint attention) are one of the earliest markers of atypical development and one of the most influential processes contributing to development in other domains (e.g., language). These early abnormalities do not appear to ameliorate over time, as older children and adults with ASD are often found to have deficits in social orienting and visually scanning social stimuli.

The *multiple processes model* of social impairments in ASD suggests that many of the social abnormalities experienced by these individuals could be attributed to deficits in domain general attentional processes (e.g., disengagement, shifting, evaluating visual cues, etc) and that low-level mechanisms cascade into higher-order deficits as children age and interact (atypically) with their worlds. Despite the intuitive appeal of this hypothesis, the exact mechanism linking low-level visual attention and social functioning has yet to be elucidated.

One of the most established ways of assessing these low-level, domain-general attentional processes is through Posner’s (1980) paradigm utilizing predictive cues and subsequent targets. This paradigm allows for the simultaneous assessment of multiple attentional mechanisms, is appropriate for children as young as seven years, and is sensitive enough to differentiate between different types of inattention. With ASD populations, Posner-style paradigms have elicited both intact and impaired cue evaluation, as well as faster and slower visual disengagement. Relevant studies utilizing other paradigms have indicated that response inhibition, the social salience of the cue, and the visual field to which attention is allocated may also influence visual attention performance. The simultaneous assessment of these constructs may be key in understanding disparate findings, as well as clarifying the link between visual attention and social development. A better understanding of this relationship would facilitate the development of interventions to target early visual attention, and potentially alter the course of neural development.

The current study. The current study aimed to address three main questions: (1) do high-functioning individuals with ASD demonstrate specific difficulty with aspects of low-level attention (i.e., disengagement, cue evaluation, response inhibition, and/or visual field differences)? (2) are attentional deficits associated with "real world" social abilities? and (3) how can this link inform our conceptualization of social impairments and interventions?

Question 1: Do high-functioning individuals with ASD demonstrate specific difficulty with aspects of low-level attention? We predicted that participants with ASD would demonstrate increased difficulty with disengagement, as measured by competing and high response salience (i.e., higher response inhibition load). We predicted that the children in the ASD group would be more impacted by the competitive and high salience cues than TD and ADHD groups, whom we predicted to be statistically similar (based on previous findings, e.g., Adólfsdóttir, Sørensen, & Lundervold, 2008). Results were examined for right and left targets separately, to probe for lateralization effects (D'Cruz et al., 2009; Vlamings et al., 2005).

We also predicted that participants with ASD would demonstrate decreased cue evaluation. We predicted a decreased effect of invalid cues for *both* the arrow and face drawings, with the children in the ASD group being significantly less impacted by the invalid cues than both the TD and ADHD groups (in which we predicted no differences). We predicted no significant effects of face versus arrow cues, because the cues were matched on luminance and complexity, therefore requiring similar visual evaluation time.

Both explicit responses and eyetracking movement data were collected. We predicted that children in the TD and ADHD groups would demonstrate more frequent anticipatory fixation changes to the predicted location of the target, despite being instructed to remain fixated on the cue. Anticipatory fixation changes were hypothesized to reflect the reflexive nature of high cue importance in these two groups, resulting from a more thorough understanding of the cue's predictiveness.

Question 2: Are attentional deficits associated with "real world" social abilities? We predicted that difficulties with disengagement and/or cue evaluation would be related to real-world social skills within individuals. Social skills were measured through behavioral and parent-report measures of social functioning.

Question 3: How can the link between visual attention abnormalities and social functioning inform our conceptualization of social impairments and interventions? Through an analysis of the collected data, we considered implications for psychosocial and behavioral interventions and future directions of needed research.

Methods

Participants. Participants included 56 school-age children and adolescents, ranging in age from eight to 18 years (M = 13.0, SD = 2.8). Participants were divided into three groups: those diagnosed with an autism spectrum disorder (ASD; n = 19), those diagnosed with attention-deficit/hyperactivity disorder (ADHD; n = 13), and those with typical development (TD; n = 24). The overall sample was predominantly Caucasian (96%), with a small portion of the participants identifying as Latino/a (4%, n = 2). The sample was also predominantly male (73%), with comparable gender ratios, $X^2(2) = 2.67$, $p = .26$, in each group (ASD n = 16; ADHD n = 10; TD n = 15). The proportion of lefthanded individuals was similar across groups, $X^2(3) = 3.51$, $p = .48$. Participants were asked to withhold stimulant medication use on the day of testing. One child with ADHD was unable to withhold attention medication (Intuniv, a non-stimulant medication prescribed for impulsivity); therefore, analyses were run with and without this participant.

Across groups, participants had a full-scale IQ of 85 or higher, as measured by the Stanford-Binet Intelligence Scales, 5th edition Abbreviated Battery (ABIQ; Roid, 2003), to limit the confounding influence of intellectual disability, and had no history of a seizure disorder. To be included in the ASD group, participants were required to meet DSM-IV-TR criteria for Autistic Disorder ($n = 14$), Asperger's Disorder ($n = 1$), or Pervasive Developmental Disorder, Not Otherwise Specified (PDD-NOS; $n = 4$). Diagnosis was confirmed using a combination of the Autism Diagnostic Observation Schedule- Module 3 (ADOS; Lord, Rutter, DiLavore, & Risi, 1999), the Autism Diagnostic Interview-Revised (ADI-R; Lord, Rutter, & Le Couteur, 1994), and expert clinical judgment. ADHD participants were included if they had a prior expert-clinician diagnosis of ADHD- Predominately Inattentive Subtype or ADHD- Combined Subtype. The Child Behavior Checklist (CBCL; Achenbach, 1991) and Conners- Revised Rating Scale (Conners, Sitarenios, Parker, & Epstein, 1998) were used to verify diagnostic status and current inattentive symptoms. One child in the ADHD group had received an educational classification and accommodations through school, rather than a formal diagnosis, and per parent report was only mildly elevated on attentional-symptom measures; therefore, analyses were run with and without this participant. Children with ADHD were excluded on the basis of a prior diagnosis of ASD or a first-degree relative with ASD. Finally, children in the TD group had developmental histories free of developmental and/or neurological problems, confirmed using the CBCL and the Social Communication Questionnaire (SCQ; Rutter, Bailey, & Lord, 2003), and had no first-degree relatives with ASD.

After initial screening, data from a total of seven children were excluded from the ASD group on the basis of low IQ ($n = 2$), unconfirmed diagnoses ($n = 2$), a history of seizures ($n = 1$), an inability to participate in testing due to anxiety ($n = 1$), and an inability to understand the experimental task demands ($n = 1$). One ADHD participant was excluded because of a past diagnosis of PDD-NOS and two TD participants were excluded on the basis of a reading disability, resulting in the final sample of 56 participants. The groups were matched for age, gender ratio, socio-economic status (SES; Hollinghead, 1975), and IQ (ABIQ), all F (2, 53)*'s* < 1.33, *p's* > .27, η^2*'s* < .04 (Table 1).

Table 1. *Participant demographics*

	ASD (n = 19)	ADHD (n = 13)	TD (n = 24)	F	p	η^2_p
Age (years)	13.3 (2.8); 7.7-17.2	12.5 (3.3); 8.2-18.3	13.0 (2.7); 8.1-17.8	0.28	0.76	0.01
Gender (male:female)	16:3	10:3	15:9	1.33	0.27	
SES	50.1 (8.0); 35-63.5	45.9 (8.5); 30-58	49.3 (8.9); 38.5-66	1.32	0.28	0.05
ABIQ[a]	102.8 (10.6); 85-127	99.8 (7.5); 85-115	105.4 (11.5); 88-139	1.25	0.30	0.04
ADOS, Social Communication[b]	10.8 (3.8); 7-20					
SCQ Total[b**]	19.7 (6.5); 9-33	5.3 (5.2); 0-18	1.3 (1.0); 0-4	86.8	< .001	0.77
CBCL Attention Problems[c**]	64.9 (9.2); 50-89	64.5 (11.2); 50-83	51.1 (2.0); 50-59	21.0	< .001	0.46

** $p < .001$ *$p < .05$

Note: Data are presented as *M (SD); Range.*

[a] ABIQ: Stanford-Binet Abbreviated IQ; standard scores have a *M* of 100 and a *SD* of 15.

[b] Social Communication Questionnaire (SCQ) scales and ADOS are presented as sum scores; higher scores indicate greater symptom severity. SCQ scores were significantly different between the ASD and TD groups, $p < .001$, between the TD and ADHD groups, $p = .02$, and between the ASD and ADHD groups, $p < .001$.

c CBCL: Child Behavior Checklist. Significant differences were between the TD and ASD groups, $p < .001$, and between the TD and ADHD groups, $p = .001$. The ASD and ADHD groups were not significantly different, $p = .91$.

Procedures. Participants were recruited through previous study participation, mailings to schools in Connecticut and Massachusetts, community groups and clinics, and by word of mouth. Testing was conducted in a laboratory at the University of Connecticut or at children's homes. Parental consent and child assent was obtained prior to participation. Data was collected as part of a larger, grant-funded study of language development; typical participation for ASD and TD groups lasted eight hours and was conducted over one to two sessions. Participants in the ADHD group received a truncated battery specific to this project; their testing lasted approximately three hours and was conducted in a single session.

Standardized measures of cognition and language. Standardized measures of cognitive and language abilities were administered to compare groups and to assess of the relationship between skills associated with early attention-based concerns (e.g., receptive language). Language abilities were characterized by the Clinical Evaluation of Language Fundamentals, Fourth Edition (CELF-4; Semel, 2003) and the Peabody Picture Vocabulary Test, Third Edition (PPVT-III; Dunn & Dunn, 1997). The CELF-4 Core Language battery consists of four subtests. For children below the age of 12-years, subtests measured skills such as following directions, word structure (i.e., morphology), recalling spoken sentences and creating sentences based on a picture and an experimenter-provided word. Adolescents over the age of 12-years completed subtests requiring them to provide word definitions and to compare the relationship between words in place of the younger directions and morphology tasks. A CELF-4 Core Language standard score was calculated based on performance and was standardized based on chronological age. The PPVT-III is a measure of receptive vocabulary that requires participants to choose a picture, out a four-picture array, that demonstrates the meaning of a given word. Both tasks provide standardized scores based on chronological age, as shown in Table 2.

Table 2. *Group performance on language and parent-report measures.*

	ASD (n = 19)	ADHD (n = 13)	TD (n = 24)	F	p	η^2_p
CELF-4 Core Language[a*]	101.6 (13.3); 78-126	104.2 (15.0); 79-130	111.4 (7.9); 97-130	3.93	0.03	0.13
PPVT-III[b]	109.6 (12.5); 83-131	115.9 (12.6); 92-131	115.9 (10.8); 100-147	1.79	0.18	0.06
NEPSY-2 TOM Verbal Raw Score[c*]	18.4 (2.8); 12-22	20.4 (1.9); 16-22	20.3 (1.8); 14-22	4.81	0.01	0.16
Joint Attention Total Score[d**]	11.3 (2.7); 8-18	17.5 (3.4); 12-22	18.4 (2.2); 14-22	40.8	< .001	0.61
SRS Total[e**]	77.0 (10.9); 56-90	57.2 (17.6); 37-85	42.5 (5.5); 34-57	47.6	< .001	0.67
BRIEF GEC[f**]	71.7 (16.6); 38-104	60.3 (10.3); 41-77	44.4 (7.5); 31-62	27.3	< .001	0.53

** $p < .001$ *$p < .05$ *Note:* Data are presented as *M (SD); Range.*

[a] CELF-4: Clinical Evaluation of Language Fundamentals, Fourth Edition. The TD and ASD groups were significantly different, $p = .005$; the TD and ADHD groups, $p = .07$, and ADHD and ASD groups, $p = .62$, were not significantly different.

[b] PPVT-III: Peabody Picture Vocabulary Test, Third Edition.

[c] NEPSY-2 TOM: NEPSY-2 Theory of Mind. Possible scores range from 0 to 22. The ASD group was significantly different than the TD, $p = .02$, and the ADHD group, $p = .03$; the TD and ADHD groups were not significantly different, $p = .90$.

[d] Possible scores range from 0 to 24. The ASD group was significantly different than the TD and ADHD groups, p's < .001; the TD and ADHD groups were not significantly different, $p = .43$.

[e] SRS: Social Responsiveness Scale. T-scores above 60 are considered in the "clinical" range. The TD group was significantly different than the ASD group, $p < .001$, and the ADHD group, $p = .02$; the ADHD and ASD groups were also significantly different, $p = .005$.

f BRIEF GEC: Brief Rating Inventory of Executive Functions, Global Executive Composite. T-scores above 65 are "clinically-significant." The TD group was significantly different than both ADHD and ASD groups, p's < .001; the ASD and ADHD groups were also significantly different, $p = .04$.

Behavioral measures of social functioning. Scores from the ADOS provided a measure of social functioning and symptom severity in the ASD group only. Raw scores were used to confirm diagnostic status. Scores on the ADOS were then transformed into a continuous severity measure, using the algorithm developed by Gotham, Pickles, and Lord (2009). All children completed the Theory of Mind (TOM) subtest of the NEPSY-2 (Korkman, Kirk, Kemp, 2007); questions on this measure tap understanding of mental states and inferred knowledge. The NEPSY-2 TOM task provides a verbal raw score, as well as a total raw score, which includes items testing facial expression perception. The verbal items are most analogous to commonly-used TOM tasks; as such, the verbal scale and total scale were analyzed separately. The NEPSY-2 TOM task yields noncontinuous percentile ranges rather than standard scores, so raw scores were converted into residualized scores, covarying for mental age; these scores were used in subsequent analyses.

All participants completed an experimental joint attention measure, described in Table 3, consisting of six naturalistic examiner-initiated prompts designed to elicit response to joint attention (Bean & Eigsti, 2012). For this measure, the participant sat across a small table from the experimenter. Prompts were embedded into other tasks during the testing session, at times when the participant was visually engaged with another task or object. Based on prior research (e.g., Hobson & Lee, 1998), prompts required participants to engage in triadic gaze (i.e., “correct response”). For example, in the “*give pen*” prompt, the correct response required that participants shift gaze from their current focus to the pen, and take the pen after it was offered by the experimenter. Responses were scored such that higher scores marked more social responses, with points awarded for each of the following: (1) engaging in triadic attention; (2) looking at the examiner's face; (3) making eye contact; and (4) offering a spontaneous, relevant verbalization (e.g., "Did you need something?"). The total score and two established subscale scores (single- and dual-shift) were used for this study, in order to assess overall joint attention behaviors, as well as responses to simple and complex items separately. Single-shift items are marked with *italics*. This measure was found to have good construct validity and inter-rater reliability. Table 2 shows group performance on social behavioral measures.

Table 3. *Joint attention prompts*

	Item	**Experimenter's Cue ("prompt")**	**Appropriate Response**	**Target Behavior**
1.	*Handshake*	E holds out hand without speaking	shake hand	Joint focus on object
2.	*Give Pen*	E hands pen to P	take pen or paper	Joint focus on object
3.	*Call Name*	State P's name when P looking elsewhere	look up at E	Disengagement
4.	*Lost pen*	Pen visible to P only; E searching for pen while holding paper; states that s/he is missing something	give pen to E	Recognition of E's need and joint focus on object
5.	Personal Object	E looks at personal item belonging to P, makes comment ("Where did you get that?")	look up at E, look at object	Joint focus on object
6.	Introduction	E introduces P to a third individual ("Did you meet _____?")	look at E, look at new individual	Joint focus and greeting

E = experimenter; P = participant

Parent-report measures of social and attentional functioning. Parents completed the SCQ and the Social Responsiveness Scale (SRS; Constantino, 2005) as measures of ASD symptom severity.

The SCQ is a 40-item yes/no screening questionnaire assessing symptoms of ASD. The SCQ provides a summary score, with higher scores indicating more severe delays and has an ASD cutoff point at 11. In addition to the standard administration, parents were asked to rate six SCQ items from 1-5 (1, "Multiple Times per Day" to 5, "Never") to provide a continuous measure of joint-attention-specific items (i.e., SCQ Likert Scale). These items were reverse coded, with higher scores being more severe.

The SRS is a 65-item questionnaire designed to measure overall social reciprocity, with specific subscales measuring social awareness, cognition, communication, and motivation. SRS *t*-scores of 59 or less are considered to be within the normal range and scores of 76 or higher are considered to be in the severely impaired range. The SRS measures social reciprocity, with higher scores indicating more significant difficulties. The SRS was included to supplement the limited variability of the SCQ in typically developing samples.

In addition to confirming sub-clinical internalizing and externalizing symptoms in the TD group, the CBCL was also used to assess the level of more general problematic behavior associated with attention and social competence. The CBCL consists of 7 open-ended and 113 Likert-scale items reflecting several aspects of behavior, including social, attention problems, aggressive, and anxious behaviors. CBCL competence scale *t*-scores above 35 are considered to be within the normal range, while CBCL syndrome scale *t*-scores below 65 are within the normal range.

The Behavior Rating Inventory of Executive Functions (BRIEF; Gioia, Isquith, Guy, & Kenworthy, 1996) parent questionnaire was used to assess attentional flexibility. The BRIEF contains items related to two aspects of executive functioning: behavioral regulation (subscales include inhibition, attentional shifting, and emotional control) and metacognition (with subscales including initiation, working memory, planning and organization, organization of materials, and self-monitoring), which combine to create a global scale. Scores are standardized based on gender and age with higher scores representing higher levels of executive dysfunction. *T*-scores above 65 are considered to be in the clinically-significant range. Group means for parent-report measures are included in Table 2.

Experimental "Rainbow Fish" task. Participants completed a modified computerized Posner paradigm (Posner, 1980). They were asked to fixate on a central cue and to "catch" a fish (target) out of their peripheral vision by clicking with a mouse when it appeared to the left or the right of the fixation cross. Cues consisted of a line drawing of a face or an arrow, matched for complexity (i.e., number of lines comprising the drawing) and luminance. A sample trial is shown in Figure 1. Each trial consisted of a fixation period (400 ms), cue presentation (150 ms), a stimulus onset asynchrony period (SOA; 450 ms), and target presentation. Target presentation lasted until a behavioral response was recorded, or for a maximum of 1700 ms. The inter-trial interval (ITI) was 130 ms.

The task included six blocks of 68 trials each, for a total of 408 trials, and lasted approximately 15 minutes. The 408 trials included 24 uncued (12 with right-sided targets) trials; in these baseline RT trials, the fixation cross remained on screen, then the target appeared to the right of left without a preceding directional cue, to measure baseline reaction time. The remaining 384 trials were cued in the four experimental manipulations: (a) validity, (b) competition, (c) response salience, and (d) social salience. For the *validity* manipulation, the cue accurately (valid; 75% of trials, n = 288) or inaccurately (invalid; 25% of trails, n = 96) predicted the location of the target. The proportion of valid to invalid trials was chosen based on previous studies (e.g., Posner, 1980) to ensure the likelihood of learning the predictive value of the directional nature of the cue. For the c*ompetition* manipulation, the cue remained on screen (competing; 50% of trials, n = 192) throughout the SOA period or disappeared (noncompeting; 50% of trials, n = 192) before the target appeared. For *response salience* (a measure of executive control), trials were parametrically varied by presenting invalid trials after either two (low salience; 50% of invalid trials, n = 144) or four (high salience; 50% of invalid trials, n = 144) valid trials. The response salience manipulation has been shown to be highly sensitive to individual differences in prior research (Eigsti, Zayas, Mischel, Shoda, Ayduk, Dadlani, et al., 2006). In such studies, presenting an increasing number of "response" trials is thought to increase the salience of a particular response, and thus increase the difficulty of generating a conflicting response on the first different trial type (e.g., responding to valid trials), the more difficult it will be to override that response for an invalid trial. For *social salience,* conditions were balanced to contain an equal number of face (n = 192) or arrow (n = 192) cues. This manipulation provided a further test of cue evaluation for social (face) versus non-social (arrow) cues. Table 4 presents a summary of experimental manipulations and Figure 2 presents the organization of experimental manipulations, through a depiction of trial subdivisions. Behavioral responses (RT and accuracy) were recorded using E-Prime.

Table 4. *Summary of experimental manipulations*

VALIDITY	***Valid* (*n* = 288)**	***Invalid* (*n* = 96)**
	Cue correctly predicts the target location	Cue incorrectly predicts the target location
COMPETITION	***Noncompeting* (*n* = 192)**	***Competing* (*n* = 192)**
	Cue disappears during SOA	Cue remains on-screen during SOA
RESPONSE SALIENCE	***Low Salience* (*n* = 48)**	***High Salience* (*n* = 48)**
	An invalid trial is preceded by two valid trails	An invalid trial is preceded by four valid trials
SOCIAL SALIENCE	***Social* (*n* = 192)**	***Non-social* (*n* = 192)**
	Face cue	Arrow cue

Figure 1. *Sample valid trial (screen images not to scale).*

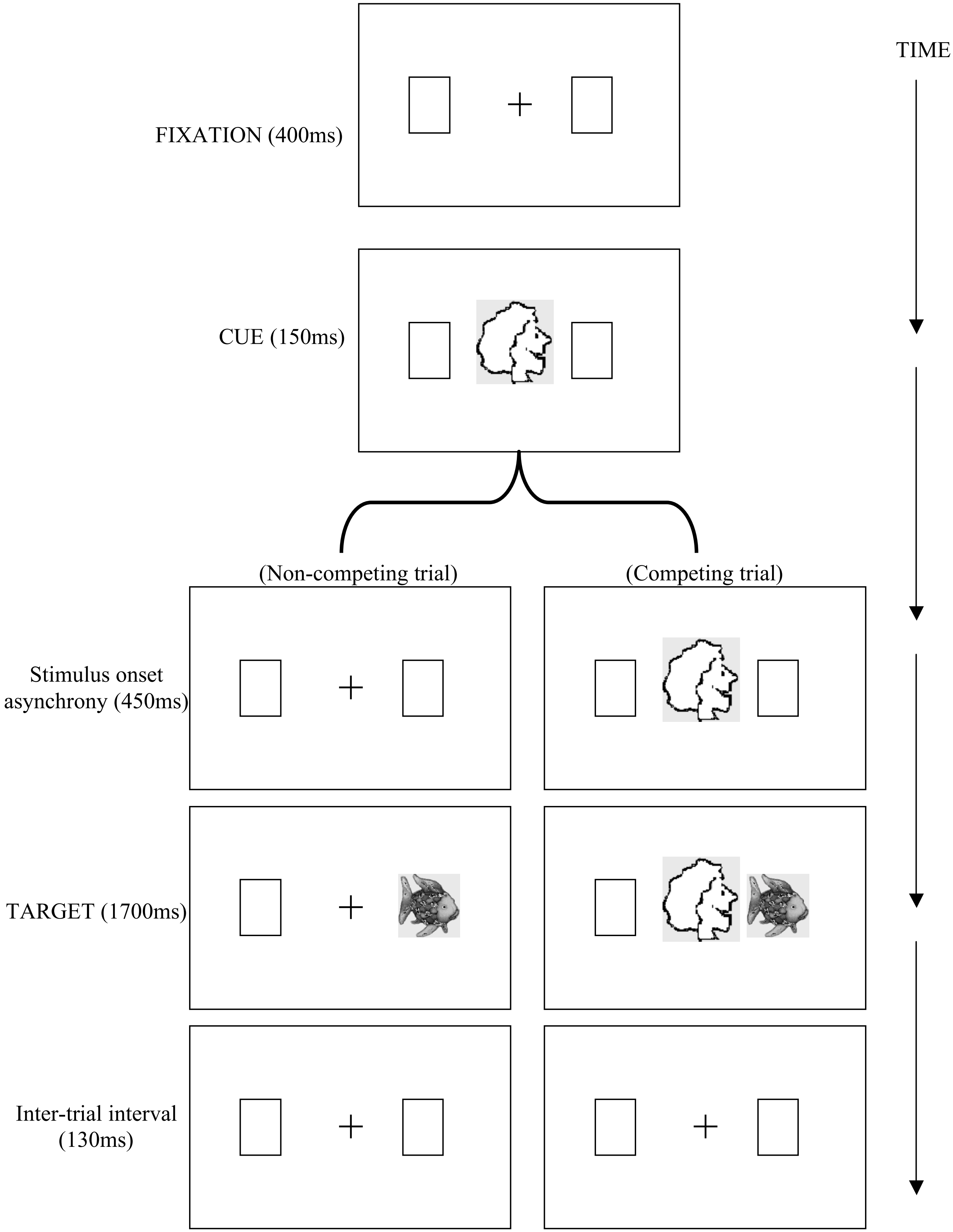
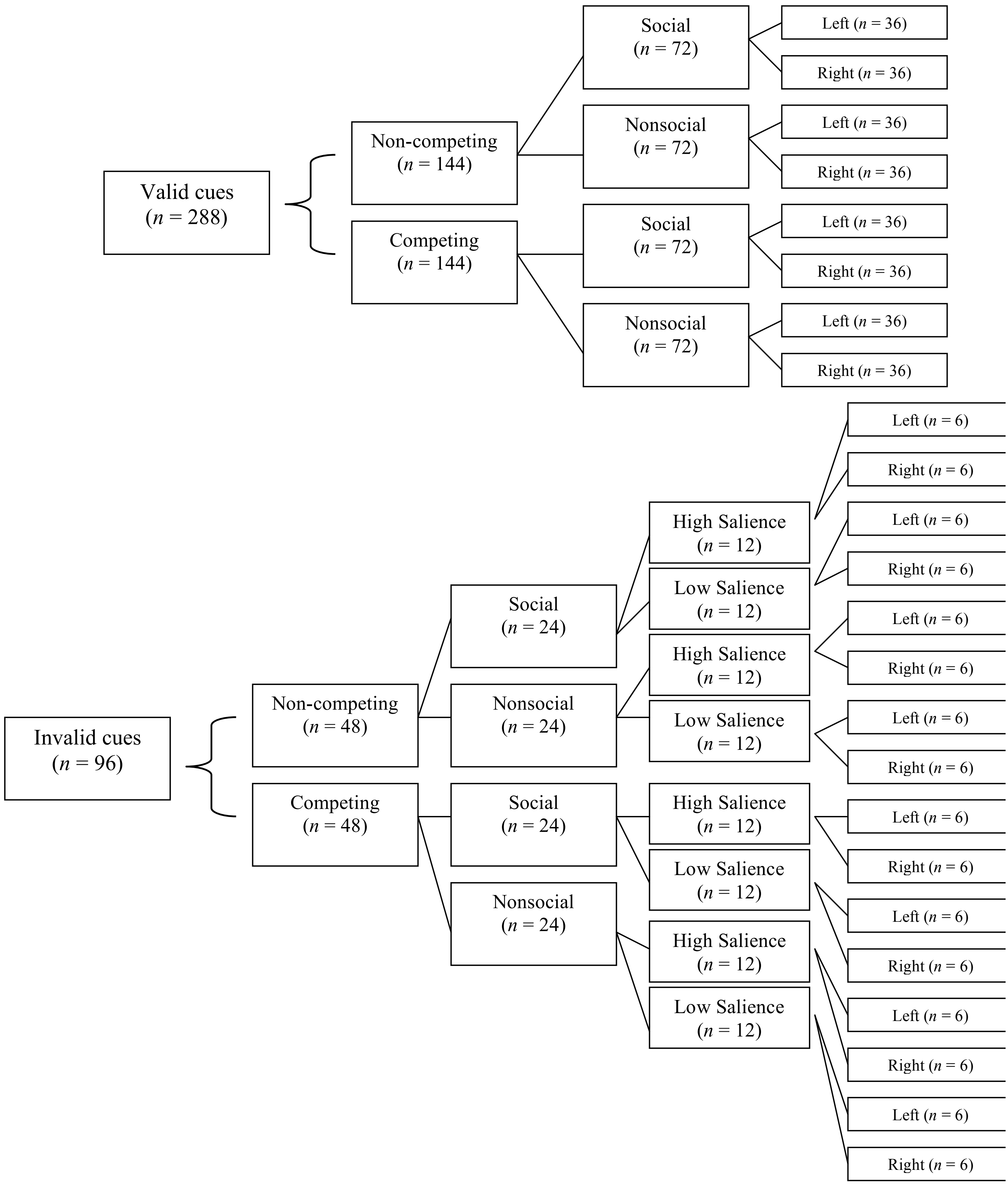


Figure 2. *Organization of experimental manipulations.*

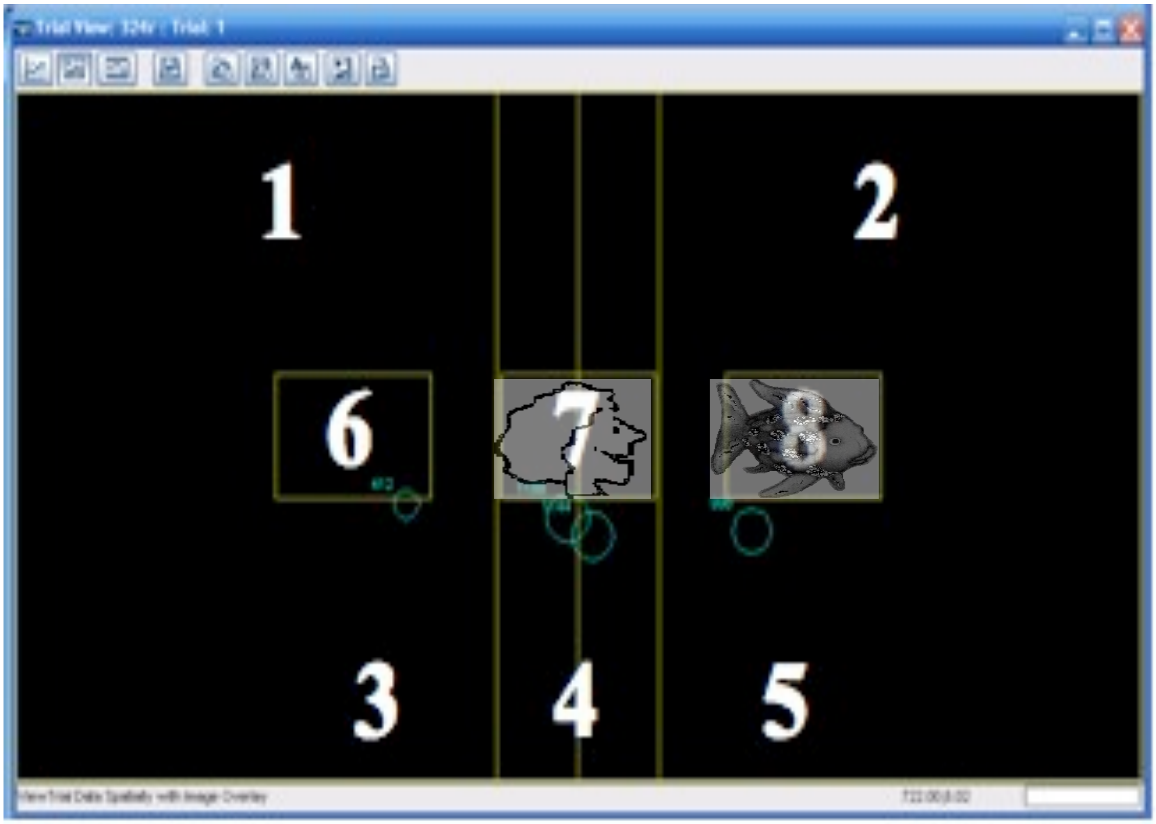


Eyetracking. Eye movements were recorded using an EyeLink 1000 desktop-mounted eye tracker, which recorded eye gaze without restricting head or body movements and with an accuracy of better than one degree. Figure 3 shows the defined regions of interest (ROIs). Eye-tracking data yielded three variables: anticipatory fixations, proportion of time spent fixated on the cue, and the number of trials with lost fixations. These variables were selected, instead of a more continuous timecourse variable, because instructions directed participants to fixate on the crosshair, which likely altered the natural timecourse of eye movements.

Anticipatory fixations began after the cue presentation (at 400 ms) and before the target onset (1000 ms). Scores are presented at proportion scores (i.e., the number of trials with an anticipatory fixation divided by the number of usable trials), in order to compare across cue types and target locations. The proportion of time spent fixated on the cue ("cue fixation") variable was defined as the proportion of the cue presentation (150 ms for noncompeting cues and 600 ms for competing cues) during which the participant was fixed on the cue location. For example, if a participant were fixated on the cue location from 400 to 500 ms on a noncompeting trial, this would yield a "cue fixation" score of 0.67. Finally, lost fixation variables were defined as (1) fixations lost prior to cue presentation (before 400 ms), (2) fixations lost after target presentation (after 1000 ms), and (3) lost fixations during the critical portion of the trial (i.e., between 400 and 1000 ms, or between cue and target presentation).

Figure 3: *Defined areas of interest for eye-tracking data.*

Note: This figure demonstrates data for one trial. Blue circles represent areas of eye fixation.



Results

<u>Preliminary analyses</u>

Errors and overall RT. As in prior research (e.g., Todd et al., 2009), all outlier responses were removed from the data. A *M* and *SD* were calculated for each participant, for each block, in order to preserve individual and across-task differences. Trials with responses more than 1.5 *SD*s above or below this mean were removed, to limit the confounding influence of a small number of trials with erroneously inflated reaction times. The number of outlier responses was tracked. Assumptions of normal distribution were assessed via group-based variable histograms and non-normally distributed variables (e.g., error variables) were transformed accordingly (Pallant, 2010). Homogeneity of variance was assessed via Levene's statistic; all main contrast variables met criteria for parametric analyses (F's < 3.0, p's > .06, with significance levels for all but left-sided responses with p's > .38). Transformed error variables also met this criteria (F's < 2.6, p's > .08), as well as overall SD variables (F's < 3.2, p's > .05). The homogeneity of overall RT variables was assessed as F's < 3.6 and p's > .04; Levene's statistics for the ASD and TD group met assumptions (F' < .01, p's > .90). All but one transformed eye-tracking variable met this assumption (lost fixations after 1000 ms, F = 4.6, p = .02; all others, F's < 2.5, p's > .09). For all transformed variables, non-parametic analyses were conducted and, in all cases, findings were unchanged.

All analyses were conducted with and without the two ADHD participants identified in the Methods sections (one of whom was taking non-stimulant medication and one of whom had an educational diagnosis); findings were unchanged, therefore, the following results include all subjects.

Behavioral responses: Error analyses. Based on total error rates, two participants were removed from analyses for having error rates greater than three *SD*s above their group means (i.e., one TD participant with an overall error rate of 0.27 and one ADHD participant with an overall error rate of 0.31). Overall error rates for each group were low, with all group means below .05.

Error trials were identified, counted and analyzed for within-group characteristics and between-group differences. Errors included (1) *incorrect* responses, defined as a participant clicking on the incorrect side, (2) *no-response* trials, and (3) *impulsive* errors, responses before participants could react to the target (e.g., prior to or within the first 100 ms of the target presentation). This cut-off was chosen to mirror previous research (e.g., Senju et al., 2004), as well as to account for both the average time needed to visually identify the stimulus and execute a response to targets outside the fixation zone (160 to 190 ms; Kosinski, 2005) and the anticipatory attention shifts that may occur in this endogenous paradigm. Total error rates (i.e., the number of errors divided by the total number of trials) were calculated. Error performance by group is shown in Table 5. Incorrect and total error rate scores variables were square root transformed, and no-response and impulsive error scores were inverse transformed to meet assumption of normal distribution.

Using the transformed variables, one-way ANOVAs assessed for group differences in error rates. There were significant group differences in the number of *incorrect* ("wrong side") responses, $F(2, 51) = 3.26$, $p = .05$. Post-hoc analyses indicated that the ASD group made more incorrect responses than the TD group, $t(40) = -2.36$, $p = .02$, and the ASD group made more incorrect responses than the ADHD group (at the trend level), $t(29) = 1.87$, $p = .07$; the TD and ADHD groups were not significantly different, $t(33) = -.24$, $p = .81$. There were no group differences in the number of *non-response* trials, $F(2, 51) = .203$, $p = .81$. There were significant group differences in the number of *impulsive* responses, $F(2, 51) = 4.88$, $p = .01$. Post-hoc analyses indicated that the ASD group made more impulsive responses than the TD group, $t(40) = 3.22$, $p = .003$, and the ADHD group made more impulsive responses than the TD group (at the trend level), $t(33) = 1.64$, $p = .11$; the ASD and ADHD groups did not differ significantly, $t(29) = -.91$, $p = .37$.

There were significant group differences on the total error rate as well, $F(2, 51) = 3.33$, $p = .04$. The ASD group made significantly more errors than the TD group, $t(40) = .85$, $p = .02$. The ADHD group was not significantly different than either the TD or ASD groups, t's < 1.21, p's > .23. Non-transformed (i.e., "raw") variables were also compared using a Kruskal-Wallis test, the non-parametric version of an ANOVA, with the same pattern of results. Overall, the ASD group the made the most errors, followed by the ADHD group, than by the TD group; however, overall error rates were very low.

Overall RT response characteristics. With errors removed, One-way ANOVAs probed for group differences in overall RT and variability. For overall RT, there were no group differences in overall RT before or after outliers were removed, $F(2, 51) = 1.67$, $p = .20$ and $F(2, 51) = 2.04$, $p = .14$, respectively. Groups were also not significantly different in their amount of overall variability, $F(2, 51) = 0.85$, $p = .43$ and $F(2, 51) = 1.66$, $p = .20$, respectively when performance was collapsed across task blocks. Finally, groups were not significantly different in their RT on baseline (non-cued trial) RT, $F(2, 51) = 2.23$, $p = .12$. Table 5 also presents RT data.

RT over the course of the task. To probe for differences in fatigue, group performance was compared over the course of the six experiment blocks using Repeated-Measures MANOVAs (with group as the between-group factor and block performance as the within-group factor). Pillai's Trace significance levels are reported throughout, as they are more robust when comparing groups with unequal n's. There was no main effect of group, $F(2, 51) = .98$, $p = .44$, confirming aforementioned results and suggesting that the groups were similar in their reaction time when all blocks were combined. Over the six blocks, there was a main effect of block on RT, $F(5, 47) = 9.66$, $p = < .001$, indicating a decrease in RT over the course of the task. Post-hoc analyses indicated that the main effect of block was only significant over the first four blocks (e.g., Block 1 to Block 2, Block 2 to Block 3, Block 3 to Block 4), F's > 4.22 and p's < .02, and there was no main effect for the final two blocks, F's < .98 and p's > .38, indicating that participants became progressively faster during the first half of the task, reaching a plateau at Block 4.

There was also a significant group by block RT interaction, $F(10, 96) = 2.33$, $p = .02$. Post-hoc analyses showed significant difference between the ADHD and TD groups, $F(5, 29) = 3.27$, $p = .02$, as well as the ADHD and ASD groups, $F(5, 25) = 3.36$, $p = .02$. The TD and ASD groups did not differ, $F(5, 36) = .36$, $p = .87$. These interactions reflect the extreme variability in reaction time of the ADHD group over the beginning of the task. Figure 4 depicts group changes in reaction time over the course of the task.[1]

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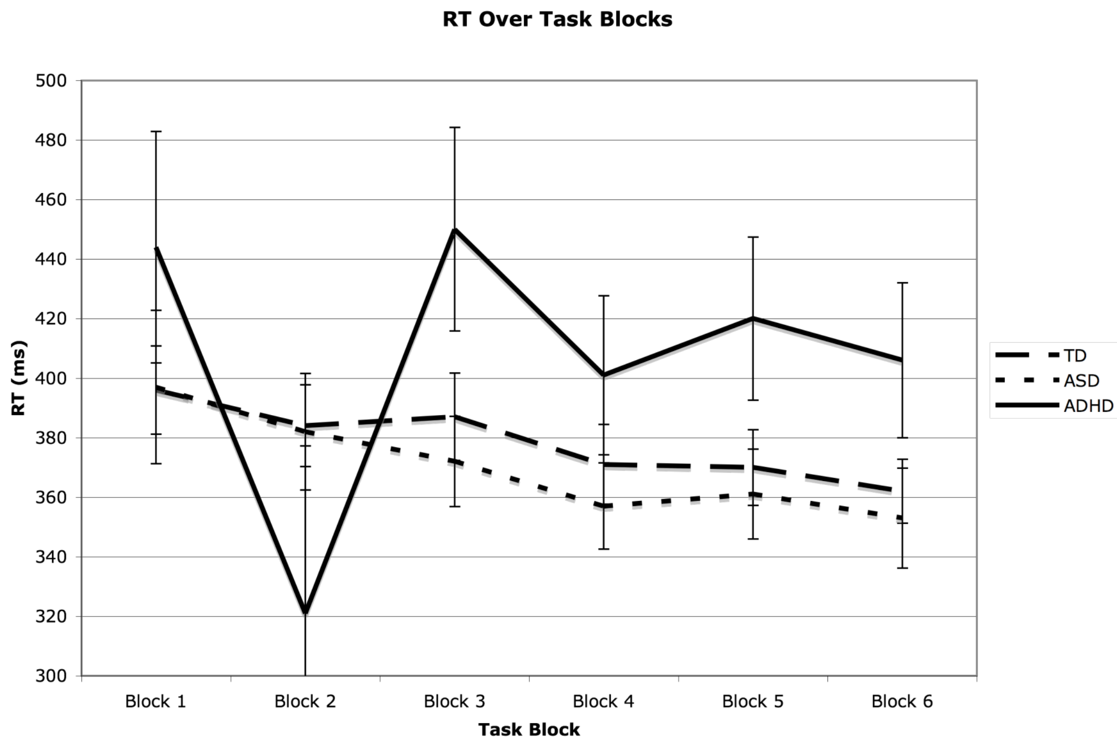
[1] Repeated-Measures MANOVAs also assessed for group changes in variability (as measured by block *SD*) over the course of the task. There was no main effect of variability, $F(5, 47) = .262$, $p = .93$, indicating no significant increases or decreases in variability across the six blocks. There was a significant main effect of group, $F(2, 51) = 3.11$, $p = .05$, indicating that the groups differed significantly in variability (when the six blocks were collapsed). Specifically, the ADHD group was more variable than the TD groups, $F(1, 33) = 4.85$, $p = .04$ and trended to be more variable than the ASD group $F(1, 29) = 3.04$, $p = .09$ (trend level). The TD and ASD groups did not differ significantly, $F(1, 40) = .404$, $p = .53$. No significant group by block *SD* interaction effect was found, $F(10, 96) = .757$, $p = .67$.

Figure 4: *Group performance in overall RT over the course of the task*



In sum, all three groups became faster over the course of Blocks 1 through 4 (by an average of 40 ms); RT changed little over the final two blocks (i.e., Block 4 through Block 6). Participants in the ADHD group showed significantly more variability in RT than both TD and ASD groups. In general, group differences were small and error rates were very low.[2]

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[2] Pearson correlations explored the relationship between error variables, general response characteristics (i.e., overall RT, baseline RT, and overall *SD*) and demographic variables (i.e., age and FSIQ). Findings indicated that participants became faster and less variable with age. All groups demonstrated a positive relationship between response errors and response time variability, suggesting that participant who make more response errors are more likely to be variable in their RT. For the TD group, error rates and variability decreased with age. For the ASD and ADHD groups, the number of no-response errors was positively associated with reaction time, indicating that participants who were more likely to not response were also more likely to be slow in their RT. Importantly, *none* of these findings suggest an accuracy-speed trade-off, characterized by a negative association between response errors and reaction time.

Table 5. *RT and error rates as a function of group.*

	ASD (n = 19)	ADHD (n = 12)	TD (n = 23)	F	p	η^2_p	Post-hoc Group comparisons
Overall RT[ab]	370 (71); 249-549	425 (107); 273-610	378 (61); 285-525	0.83	0.44	0.03	
Overall SD*[ab]	96 (27); 69-158	112 (48); 54-218	91 (30); 44-166	3.11	0.05	0.11	ADHD > ASD, TD
Baseline RT[ac]	466 (82); 354-646	532 (154); 318-820	461 (75); 318-595	2.23	0.12	0.08	
No-response errors[d]	2.4 (3.1); 0-9	2.3 (3.4); 0-11	1.8 (3.2); 0-14	0.20	0.82	0.01	
Impulsive errors*	4.8 (5.7); 0-23	3.8 (4.2); 0-13	1.9 (4.0); 0-14	4.88	0.01	0.16	ASD, ADHD > TD
Incorrect errors*	13.3 (9.0); 0-32	7.3 (5.6); 0-16	7.4 (7.9); 0-25	3.26	0.05	0.11	ASD > ADHD, TD
Total error rate*	.05 (.03); .00-.12	.03 (.02); .01-.07	.03 (.03); 0-.13	3.33	0.04	0.12	ASD > TD

** $p < .001$ *$p < .05$

Note: Data are presented as *M (SD); Range.*

[a] Reaction time (RT) and standard deviation (SD) scores are presented in ms and represent group performance after outliers were removed.

[b] Overall RT and SD significant levels were calculated using a Repeated-Measures MANOVA group effect.

[c] Group differences in baseline RT were calculated using a One-Way ANOVA.

[d] All error variables are presented as a sum, with the exception of Total error rate; the Total error rate is the Total number of errors divided by the total number of trials (i.e., 408); group differences in error variables were calculated using One-Way ANOVAs.

RT as a function of condition

Analytic approach. Repeated-Measures MANCOVAs, with baseline RT as a covariate, assessed differences in group performance as a function of experimental condition. Baseline RT was chosen as a covariate in order to compare performance across a large age range and to assess the *cost* of experimental manipulations, beyond the effect of pure motor response speed. Again, significance levels are presented as Pillai's trace values. The two participants with extremely high error-rates were excluded. Analyses were also conducted with and without the two ADHD participants described in the inclusionary criteria portion of the Methods section (i.e., one child who received an informal, academic diagnosis and one child who was unable to withhold non-stimulant medication on the day of testing). Findings with and without these two participants were identical; therefore, results are presented with these two subjects included. Also, due to the small sample size and extreme variability characteristic of the ADHD group, post-hoc interaction analyses were conducted to assess two-group comparisons, as well.

Main effect of group. Consistent with earlier findings, there were no group effects for all the following condition contrasts, F's < .22 and p's > .81. Table 6 shows RTs by group for each experimental condition.

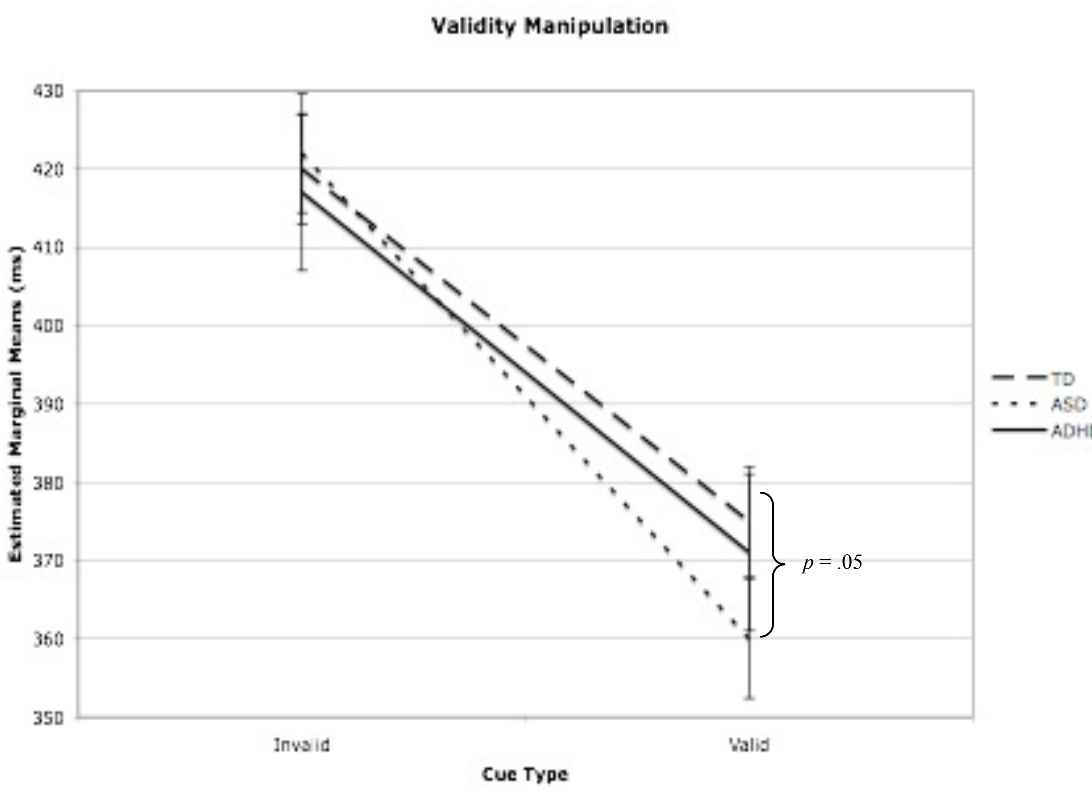
Table 6. *Group RTs for variables associated with the experimental manipulations.*

	ASD (n = 19)	ADHD[c] (n = 12)	TD (n = 23)	F	p	η^2_p
Invalid Cues[ab]	412 (74); 305-616	460 (128); 299-692	406 (69); 304-531	1.67	.20	.07
Valid Cues	352 (69); 227-524	406 (98); 262-566	364 (60); 276-522	2.06	.14	.06
Competing Cues	394 (74); 289-591	452 (120); 286-643	405 (69); 296-533	1.84	.17	.07
Non-Competing Cues	390 (69); 277-580	432 (115); 287-657	379 (60); 293-523	1.88	.16	.07
High-Salience Cues	414 (69); 314-599	462 (126); 304-688	409 (67); 310-527	1.75	.19	.06
Low-Salience Cues	410 (80); 296-633	458 (130); 296-696	403 (71); 298-544	1.57	.22	.06
Arrow Cues	397 (73); 279-598	441 (118); 289-677	392 (63); 298-524	1.56	.22	.06
Face Cues	386 (70); 277-572	442 (117); 284-635	391 (66); 291-532	1.98	.15	.07
Left-Appearing Targets	393 (64); 280-544	439 (114); 277-647	395 (61); 299-527	1.63	.21	.06
Right-Appearing Targets	391 (82); 289-626	444 (122); 295-652	389 (69); 290-530	1.82	.17	.07

** $p < .001$ *$p < .05$; *Note:* Data are presented as *M (SD); Range*.
[a] Reaction time (RT) and standard deviation (SD) scores are presented in ms and represent group performance after outliers were removed.
[b] Group differences in baseline RT were calculated using a One-Way ANOVA.
[c] Despite the ADHD group showing consistently slower RTs, ANOVAs between the ADHD group and the other two groups individually failed to meet $p < .05$ significance.

Invalid versus Valid cues. There was a significant main effect of valid versus invalid cues, $F(1, 50) = 13.87$, $p < .001$, such that all participants responded more slowly to invalid cues. There was no group by condition interaction effect when all three groups were compared, $F(2, 50) = 2.02$, $p = .14$. Post-hoc examination of this finding revealed a significant interaction effect between the TD and ASD groups, $F(1, 39) = 3.63$, $p = .05$. There was no interaction effect between the TD and ADHD groups, $F(1, 32) = .001$, $p = .98$, nor was there an interaction between the ADHD and ASD groups, $F(1, 28) = 2.03$, $p = .17$, as seen in Figure 5. Post-hoc evaluation of the data (as displayed in Table 6) indicated that the ASD group experienced a greater cost than the TD group when the cue incorrectly predicted the target location; the ADHD group was not significantly different than either the TD or ASD group (i.e., validity cost: ASD > TD).

Figure 5: *Group performance, Validity manipulation*



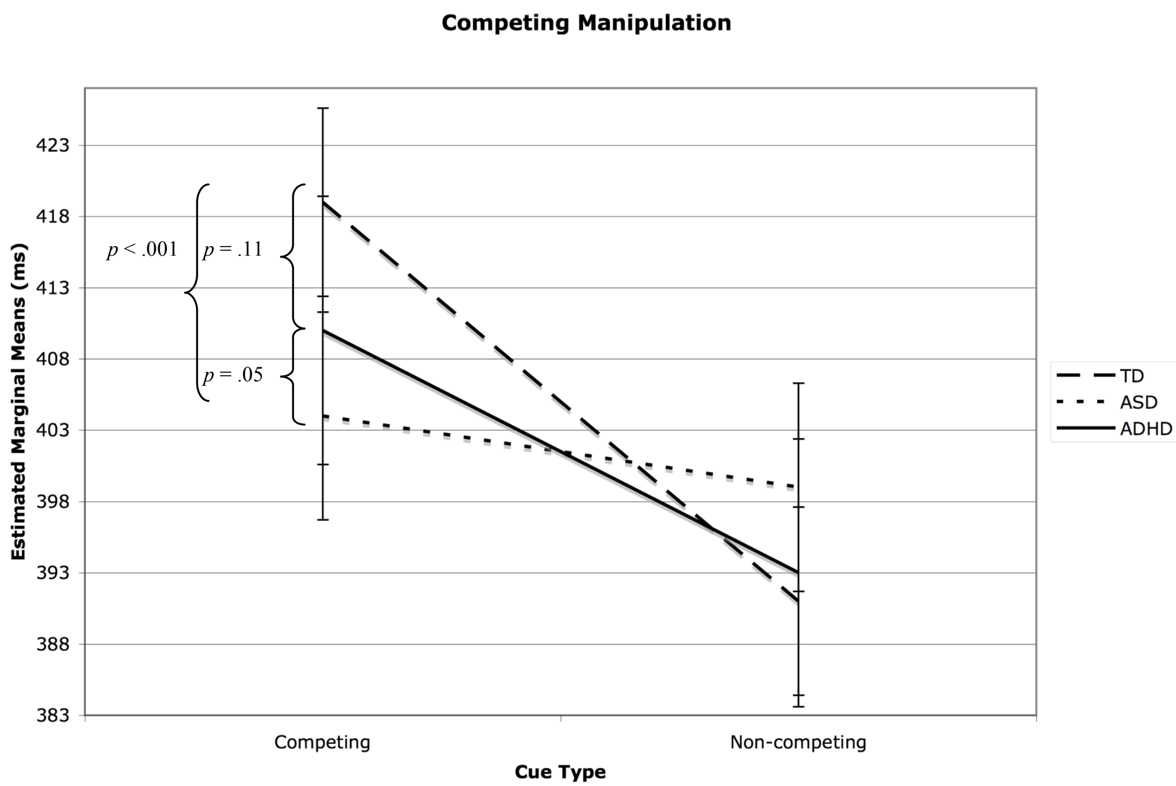
The validity condition was examined for arrow and face cues separately. The main effect of condition was significant for arrow cues, $F(1, 28) = 11.56$, $p = .002$, and for face cues, $F(1, 28) = 7.69$, $p = .01$. There was no group by condition interaction effect when all three groups were entered, for the arrow cues, $F(2, 50) = 2.14$, $p = .13$, nor for the face cues, $F(2, 50) = 1.53$, $p = .23$, cues. Post-hoc analyses showed a significant interaction effect when comparing the TD and ASD groups directly for arrow cues, $F(1, 39) = 3.98$, $p = .05$, and at the trend level for face cues, $F(1, 39) = 2.75$, $p = .105$. Although the pattern of results remained for both cues, these findings indicate that the greater invalid cost experienced by the ASD group was driven primarily by arrow cues.

Finally, the validity manipulation was assessed for non-competing cues only, in order to illuminate the contradictory findings by Landry and colleagues (2009) and Wainwright-Sharp and Bryson (1993). Recall that the first study reported that, with a cue duration of 150 ms, ASD participants were able to successfully "read" the meaning of the cue (as demonstrated by a validity effect). In contrast, with a duration of 100 ms, the ASD group exhibited no validity effect. Therefore, a Repeated-Measures MANCOVA, with baseline RT as the covariate, assessed group differences for non-competing trials only (i.e., cues presented for 150 ms). The main effect of cue (i.e., validity effect) was significant, $F(1, 50) = 7.04$, $p = .01$. The group by condition (i.e., validity) interaction dropped to trend-level significance, $F(2, 50) = 2.51$, $p = .09$; however, the pattern of findings is consistent with aforementioned results. Again, the ASD group demonstrated a greater cost for invalid cues than the TD group, $F(1, 39) = 6.05$, $p = .02$. There was no difference for ASD versus ADHD groups, $F(1, 28) = .43$, $p = .52$, nor for the TD versus ADHD groups, $F(1, 32) = .82$, $p = .37$, suggesting that the ADHD group demonstrated a validity cost in between the ASD and TD groups. Although this analysis cannot shed light on the difference between 100 and 150 ms raised in previous literature and the longer cue duration in this paper overlaps with target presentation, it does suggest that the finding reported in this sample is not entirely attributable to longer cue presentations. These findings indicate that, consistent with results from Landry and colleagues in 2009, the ASD group is able "read" brief visual cues (of 150 ms).

Competing versus Non-competing cues. There was a significant main effect of cue for the competing versus non-competing conditions, $F(1, 50) = 7.50$, $p = .009$. Across groups, participants responded more slowly to competing cues. There was a significant interaction between group and cue type, $F(2, 50) = 10.59$, $p < .001$, such that the TD and ADHD groups showed a significantly greater competition cost than the ASD group. Specifically, there was a significant interaction effect between the TD and ASD group, $F(1, 39) = 27.76$, $p < .001$, as well as between the ADHD and ASD group, $F(1, 28) = 4.30$, $p = .05$. The interaction effect between the TD and ADHD group was not significant, $F(1, 32) = 2.74$, $p = .11$. The TD and ADHD groups demonstrated a significantly greater cost than the ASD group when the cue remained on screen, with the TD group being the most impacted of the three (i.e., competing cost: TD $\geq$ ADHD > ASD). Table 6 shows group RTs for each condition and Table 7 shows group interactions across all experimental manipulations.

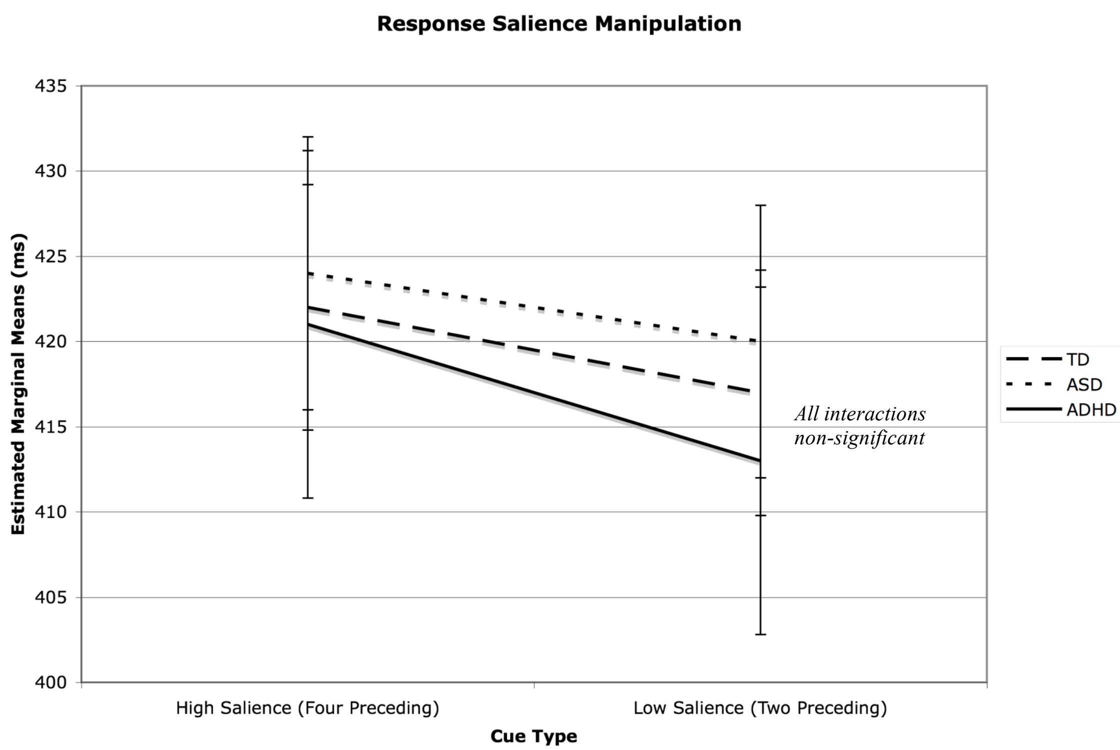
The competition effect was examined for arrow and face cues separately, to assess for response differences depending on the social or non-social nature of the cue. For the competing manipulation, the interaction effect remained significant for both arrow, $F(2, 50) = 4.69$, $p < .01$, and face, $F(2, 50) = 6.42$, $p < .003$, cues. In both cases, the TD group continued to be the most impacted by the presence of the competing cue, as seen in Figure 6.

Figure 6: *Group performance, Competing manipulation*



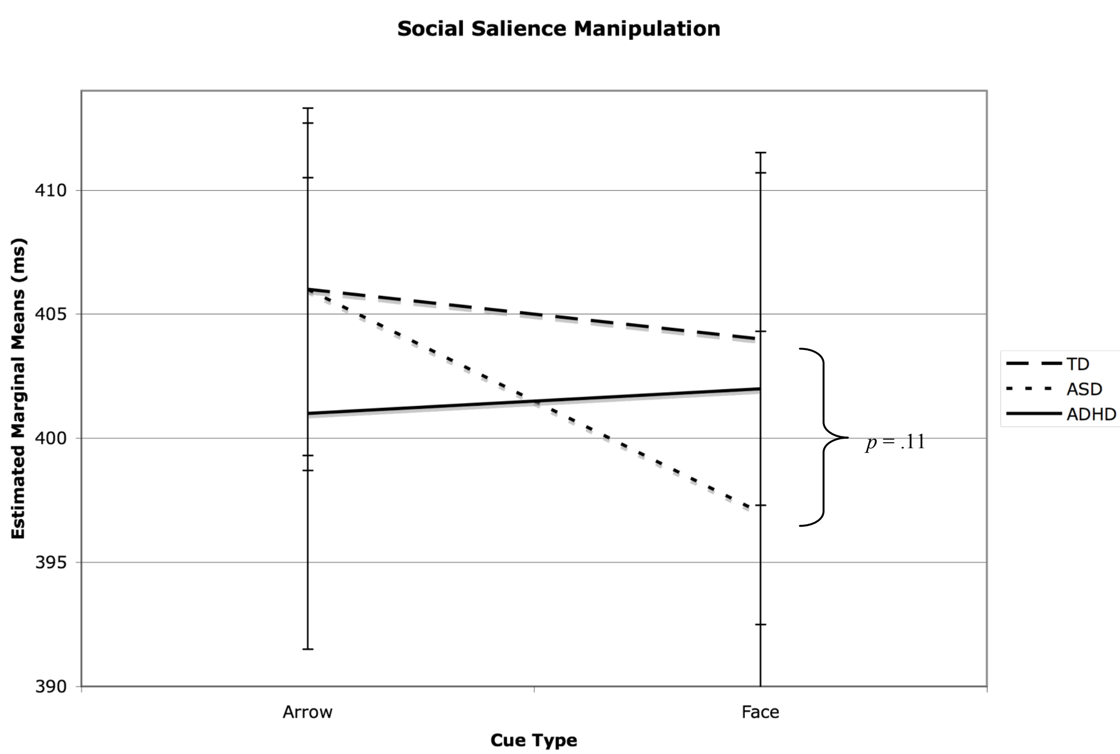
Invalid trials with High- versus Low-Salience (Response Salience). When comparing RTs for invalid trials with low-salience (i.e., two preceding valid cues) versus high-salience (i.e., four preceding valid cues) responses, there was a significant main effect for cue type, $F(1, 50) = 5.29$, $p = .03$. Across all groups, participants responded more slowly in the high salience (i.e., four-preceding valid cues) trial condition (when they had to inhibit a high-salience response) relative to the low-salience condition. There was no interaction of cue and group, *F*(2, 50) = .17, *p* = .85, indicating that the three groups were similarly impacted by the high- and low-salience manipulation.

Figure 7: *Group performance, Response salience manipulation*



Arrow versus Face cues (Social Salience). When comparing RTs for arrow and face cues, there was no main effect for cue type, *F*(1, 50) = .07, *p* = .80. Across all groups, participants responded similarly to arrow and face cues. There was also no group by condition interaction effect, *F*(2, 50) = 1.58, *p* = .22. Comparing TD and ASD groups, there was a trend level interaction effect, *F*(1, 39) = 2.72, *p* = .11. The ASD group responded to arrow cues more slowly than face cues, while the TD group responded similarly to both (i.e., the ASD group showed a greater "cost" for arrow cues than the TD group). The ASD group was significantly slower for arrow cues than face cues, $t(18) = 2.87$, $p = .01$; the TD group did not demonstrate a difference in RT for arrow and face cues, $t(22) = .275$, $p = .79$. There was a similar trend-level interaction between the ADHD and ASD groups, $F(1, 28) = 2.26$, $p = .14$, with the ASD group showing a greater difference for arrows versus faces than the ADHD group, for whom those conditions did not differ, $t(11) = .139$, $p = .89$. The TD and ADHD groups did not differ, $F(1, 32) = .10$, $p = .76$. Although not meeting criteria for significant interactions at the $p < .05$ level, these trend-level findings indicate that the ASD group responded to face cues more quickly than arrow cues, to a greater degree than their non-ASD counterparts.

Figure 8: *Group performance, Social salience manipulation*



In sum, all experimental contrasts yielded significant main effects, except for RTs to arrow versus face cues. Across the three groups, participants were slower to respond with competing cues, invalid cues, and high salience cues. Significant interactions indicated that the ASD group was *less* impacted by the presence of the competing cues than both the TD and ADHD groups. The ADHD group also demonstrated a decreased cost for competing cues (at the trend level) than the TD groups. The ASD group demonstrated an increased cost (or impact) for invalid cues, compared to the TD group, as well as for arrow cues (at the trend level) compared to both non-ASD groups.

Right- versus Left-Appearing Targets. When comparing RTs for trials with right-sided and left-sided targets using a Repeated-Measures MANCOVA (with baseline RT as a covariate), there was a significant main effect for target location, $F(1, 50) = 6.20$, $p = .02$, such that all participants responded more slowly to left-appearing targets. Recall that all participants responded with their right hand. There was no group by condition (i.e., right- or left-sided targets) interaction, $F(2, 50) = .09$, $p = .91$, demonstrating that all three groups were similarly slower for targets in the left visual field. These findings remained when analyses were run with only right-handed participants; again, there was a significant main effect for target location, $F(1,40) = 4.03$, $p = .05$, but no group by condition interaction, $F(2, 40) = .686$, $p = .51$.

Table 7. *Interaction effects for the experimental manipulations; comparing all groups.*

	ASD (n = 19)	ADHD (n = 12)	TD (n = 23)	F	p	Post-hoc Group Comparison[h]
Validity[abc]	60 (26); 19-110	54 (42); 12-141	42 (31); 9-160	2.02	.14	ASD > TD
Competition[d]	4 (14); -15-47	20 (21); -14-55	27 (17); -39-53	10.6	< .001	TD ≥ ADHD > ASD
Response Salience[e]	4 (19); -50-24	4 (19); -19-35	6 (17); -30-33	0.17	.85	TD = ADHD = ASD
Social Salience[f]	-10 (15); -35-13	1 (25); -54-44	-1 (18); -52-32	1.58	.22	ASD ≥ TD
Target Location[g]	-3 (34); -68-82	5 (28); -36-69	-5 (21); -39-53	0.09	.91	TD = ADHD = ASD

** $p < .001$ * $p < .05$; *Note:* Data are presented as *M (SD); Range.*
[a] Reaction time (RT) and standard deviation (SD) scores are presented in ms and represent group "cost" associated with the experimental manipulation.
[b] Group differences in cost were assessed using the interaction effect in a Repeated-Measured MANCOVA (with baseline RT as the covariate); p values represent the interaction effect when all three groups are compared.
[c] Validity cost = invalid cue RT minus valid cue RT.
[d] Competition cost = competing cue RT minus non-competing cue RT.
[e] Response Salience cost = high-salience cue RT minus low-salience cue RT.
[f] Social Salience cost = face cue RT minus arrow cue RT.
[g] Target location cost = RT for right-appearing targets minus RT for left-appearing targets.
[h] > or < indicate significant interactions at the $p < .05$ level; ≥ or ≤ indicate trend level interactions.

RT for the right visual field by condition. In order to explore the aforementioned finding, suggesting that participants respond more quickly to targets in the right visual field, the experimental contrasts were explored separately for the right- and left-visual field. For example, competing and non-competing cues were balanced for the number of times that the target appeared on the right or the left side. By isolating trials during which the target appeared in the right or left side of the screen, the experimental contrasts could be examined for any differences related to visual field laterality. Only right-handed participants were included in the following analyses, in order to better interpret the findings with respect to laterality, yielding samples of 19 TD, 14 ASD, and 11 ADHD participants. Repeated-Measures MANCOVAs, with baseline RT for right-sided targets as a covariate, assessed for main effects of cue manipulation and group differences in cost. Consistent with previous findings, all group effects were non-significant, F's < .91, p's > .41. Analyses were conducted with and without two ADHD participants noted in the Methods; findings were unchanged and, therefore, results are presented with the full sample to preserve power.

Invalid versus valid cues (for targets in the right visual field). When comparing RTs for invalid versus valid cues and right-appearing targets, there was a significant main effect of cue, $F(1, 40) = 5.38$, $p = .03$. This finding suggests that, across all groups, participants responded more slowly to invalid cues when targets appeared in the right visual field. There was no group by condition interaction effect when comparing all three groups, $F(2, 40) = 1.69$, $p = .20$. Post-hoc examination of this finding revealed a significant group by condition interaction effect for the TD and ASD groups, $F(1, 30) = 7.97$, $p = .008$; the ASD group demonstrated a significantly greater cost for invalid cues

(53 versus 35 ms, on average). There was no group by condition interaction effect between the TD and ADHD groups, $F(1, 27) = .821$, $p = .37$, nor between the ADHD and ASD groups, $F(1, 22) = .285$, $p = .60$. These significant findings demonstrated that, when the target appears in the right visual field, the ASD group experienced a significantly greater cost than the TD group when the cue incorrectly predicts the target location; the ADHD group was not significantly different than either the TD or ASD group.

Competing versus non-competing cues (for targets in the right visual field). When comparing RTs for trials with competing versus non-competing cues and right-appearing targets, there was no main effect of cue, $F(1, 40) = .223$, $p = .64$. This non-significant finding appears to be the result of dramatic differences between group performance; both the ASD and ADHD showed a lesser impact of competing cues than the TD group. There was a trend level interaction effect when comparing all three groups, $F(2, 40) = 2.85$, $p = .07$. When comparing the TD and ASD groups directly, there was a significant main effect of cue, $F(1, 30) = 5.71$, $p = .02$, with slower RTs for competing cues. There was a significant group by condition interaction effect as well, $F(1, 30) = 5.42$, $p = .03$, indicating that the TD group demonstrated a greater cost for competing cues ($M = 23$ ms, $SD = 25$ ms) than the ASD group ($M = 3$ ms, $SD = 19$ ms). The ADHD and ASD group did not differ, $F(1, 22) = .09$, $p = .77$, nor did TD and ADHD groups, $F(1, 27) = 1.70$, $p = .20$. When targets appeared in the right visual field, the TD group experienced a significantly greater competition effect than the ASD group. Although the interaction between the TD and ADHD groups was not significant, the pattern of findings between these participants was consistent with aforementioned bilateral findings and may reflect a loss of power with this smaller subsample of participants.

Invalid cues with High- versus Low-Response Salience (for targets in the right visual field). When comparing RTs for low-salience (i.e., two preceding valid cues) and high-salience (i.e., four preceding valid cues) trials when the target appeared in the right visual field, there was no main effect for cue type, $F(1, 40) = 1.19$, $p = .28$. There was no group by condition interaction effect, $F(2, 40) = 2.22$, $p = .12$, indicating that the three groups were similarly impacted by the high- and low-salience manipulation. When comparing the TD and ASD groups directly, there was a significant main effect of cue, $F(1, 30) = 5.60$, $p = .03$, with slower RTs for high-salience cues. There was no group by condition interaction effect, $F(1, 30) = .236$, $p = .63$, reflecting similar high-salience cost for the TD and ASD groups. There was also no interaction effect between the ASD and ADHD groups, $F(1, 22) = 1.74$, $p = .20$. In contrast, the interaction effect between the ADHD and TD groups reached trend level significance, $F(1, 27) = 3.22$, $p = .08$, reflecting the ADHD groups tendency to be more impacted by the high-salience manipulation (with average costs of 13 and -2 ms, respectively).

Arrow versus Face cues (for targets in the right visual field). When comparing targets in the right visual field, there was no main effect for cue type, $F(1, 40) = .19$, $p = .67$. This finding suggests that, across all groups, participants responded similarly to arrow and face cues. Also, there was no group by condition interaction effect, $F(2, 40) = .63$, $p = .54$. Therefore, when the target appears in the right visual field, RTs for arrow and face cues were similar across groups.

In sum, for targets in the right visual field, all participants had slower RTs for invalid cues and high-salience trials. Competing cues also resulted in a significant main effect when directly comparing the TD and ASD groups. Significant interactions suggest that ASD participants, compared to their TD counterparts, showed a lesser cost for competing cues and a greater cost for invalid cues. Compared to the TD group, the ADHD group demonstrated a trend to be more impacted by the high-salience cues. All interaction effects between the ADHD and ASD groups failed to reach statistical significance. Although significance levels of the examined main and interaction effects varied, possibly due to the reduced power of this smaller sample and the subsequent enhanced impact of the ADHD groups variability, the pattern of findings in the right-visual field was generally consistent with the aforementioned bilateral findings.

RT for the left visual field by condition. For this set of analyses, trials during which the target appeared in the left side of the screen were isolated. Again, only right-handed participants were included in the following analyses, in order to better interpret the findings with respect to laterality, resulting in the inclusion of 19 TD, 14 ASD, and 11 ADHD participants. Repeated-Measures MANCOVAs, with baseline RT for left-sided targets as a covariate, assessed for main effects of cue manipulation and group differences in cost. Consistent with aforementioned findings, there were no main effects of group, F's < .59, p's > .56. Analyses were conducted with and without the two ADHD participants with questionable inclusionary criteria, identified in the Methods section. Findings were generally unchanged, so participants were included to preserve adequate power; one set of analyses (i.e., competing cue manipulation) changed significance levels, so findings are reported both with and without these identified cases.

Invalid versus valid cues (for targets in the left visual field). When comparing RTs for invalid and valid cues for left-appearing targets, there was a significant main effect of cue, $F(1, 40) = 4.19$, $p = .05$. This finding suggests that, across all groups, participants responded more slowly to invalid cues. There was also a significant group by condition interaction effect when comparing all three groups, $F(2, 40) = 4.61$, $p = .02$. Post-hoc examination of this finding revealed significant interaction effects between the TD and ASD groups, $F(1, 30) = 7.73$, $p = .009$, and between the ASD and ADHD groups, $F(1, 22) = 5.38$, $p = .03$; the ASD group demonstrated a significantly greater cost for invalid cues than both other groups. There was no interaction effect between the TD and ADHD groups, $F(1, 27) = .96$, $p = .34$. These significant findings demonstrated that, when the target appears in the left visual field, the ASD group experienced a significantly greater cost than the TD and ADHD groups when the cue incorrectly predicted the target location (with average costs of 66, 49, and 41 ms, respectively).

Competing versus non-competing cues (for targets in the left visual field). When comparing RTs for trials with competing versus non-competing cues and left-appearing targets, there was a trend level main effect of cue, $F(1, 40) = 3.33$, $p = .08$. This finding reflects the competing cost experienced by the TD group, with the ASD group showing a lesser impact of competing cues. When comparing all three groups, there was no group by condition interaction effect, $F(2, 40) = 1.10$, $p = .34$; when the two ADHD participants were removed, this interaction effect was significant, $F(2, 38) = 6.29$, $p = .004$. When comparing the TD and ASD groups directly, there was a significant group by interaction, $F(1, 30) = 13.73$, $p = .001$; the TD group demonstrated a greater cost for competing cues (30 ms) than the ASD group (4 ms). The ADHD group demonstrated significantly lower cost for competing cues (-16 ms) than their ASD counterparts, $F(1, 20) = 5.66$, $p = .03$. There was no interaction effect between the TD and ADHD, $F(1, 25) = .75$, $p = .40$, confirming similar competing cost between these two groups. These findings demonstrated that, when targets appear in the left visual field, the TD experienced a significantly greater cost than the ASD group when the cue remains on screen. The ADHD group did not demonstrate the predicted pattern.

Invalid cues with High- versus Low-Response Salience (for targets in the left visual field). When comparing RTs for low-salience (i.e., two preceding valid cues) versus high-salience (i.e., four preceding valid cues) cues when the target appeared in the left visual field, there was no main effect for cue type, $F(1, 40) = .953$, $p = .34$. Also, there was no group by condition interaction effect, $F(2, 40) = .462$, $p = .63$, indicating that the three groups were similarly impacted by the high- and low-salience manipulation. All two-group comparisons also yielded no interaction effects, with F's < .83 and p's > .37. These findings indicate that, when targets appear in the left visual field, the high response salience manipulation does not appear to affect RT for any of the three groups.

Arrow versus Face cues (for targets in the left visual field). When comparing RTs for arrow and face cues when the target appeared in the left visual field, there was no main effect for cue type, $F(1, 40) = 1.92$, $p = .17$; this main effect approached trend level significance when the two questionable ADHD participants were excluded, $F(1, 38) = 2.87$, $p = .10$. This finding suggests that, across all groups, participants had a tendency to respond more quickly to face cues when targets appeared in the left visual field. There was no group by condition interaction effect, $F(2, 38) = 1.08$, $p = .35$. All two-group comparisons also yielded no interaction effects, with F's < 1.96 and p's > .17. Therefore, when the target appears in the left visual field, the cost associated the arrow cues was similar across groups.

In sum, for trials with left-appearing targets, several significant main effects emerged: slower RTs were found for invalid cues, competing cues and arrow cues. Significant group interactions also emerged. When comparing the TD and ASD groups, the ASD groups demonstrated a significantly greater invalid cost and a significantly reduced competing cost when compared to their TD counterparts. Compared to the ADHD group, the ASD group again demonstrated a significantly greater invalid cost. The ADHD and TD participants did not show any significant differences in their performance on the experimental manipulations.

Comparing findings from the right versus left visual field. When comparing findings between the right and left visual field, there were both similarities and differences in the pattern of results. First, main effects (across group) for competing and invalid cues were present in both visual fields. In contrast, the effect of response salience was present for right-sided targets only; the effect of social salience was present for left-sided targets only. When comparing performance between groups, significant group interaction effects were present in both visual fields. Compared to their TD peers, the ASD group had a relatively *greater* slowing for *invalid* cues and *less* slowing for *competing* cues in both visual fields. In the right visual field, the ADHD group demonstrated a significantly greater impact of high response salience cues, compared to their TD counterparts. For the ASD versus ADHD comparison, the groups differed only for left-appearing targets, for which there was a greater cost of invalid cues.

Comparing lateralized findings to bilateral findings. The main effect of competing and invalid cues affected performance in both visual fields. The bilateral main effect of cue for high-salience trials was driven primarily by targets on the right side.

Face and arrow cues (i.e., social salience) did not differ in the bilateral analyses, but there was a difference in the left visual field. For group by condition interaction effects, the ASD group's decreased cost for competing cues and increased cost for invalid cues when compared to their TD counterparts was present on both sides. The ADHD group, in contrast, did not differ from the TD group when responding to targets on the left side (as described above). For response salience, there was an interaction between group and condition for the right side only.

In sum, lateralized findings are consistent with the bilateral effects of competition and validity. In contrast, response salience and social salience showed lateralization differences. These findings suggest that, when targets appear in the right visual field, the ADHD and TD groups differed, potentially implicating a left hemispheric abnormality in primary inattention. In contrast, the ASD and TD groups differed in *both* visual fields, indicating a more global abnormality in their reaction to visual information.

Relationship between "cost" of experimental manipulations and measures of higher-order functions. In order to assess the relationship between performance on experimental manipulations and measures of social and behavioral functioning, the five experimental manipulations were transformed into RT difference scores, as follows: *validity;* invalid minus valid; *competing*: competing minus non-competing; *response salience*: high- minus low-salience; and *social salience*: face minus arrow. Two of the "cost" variables were transformed (because they were not normally distributed) in order to utilize parametric techniques: the validity-cost variable was square-root transformed and the response-salience cost variable was reflect-square-root transformed. As a result, correlations involving the response-salience variable were interpreted in the opposite direction, to reflect the relationship with the original variable. Spearman's rho correlations were conducted for untransformed variables; findings were consistent with parametric findings, therefore, Pearson correlations are reported for power and covariate capabilities. All scatterplots for significant correlations were visually inspected for artifacts. Finally, due to the large number of correlations examined in these analyses, only correlations meeting $p < .05$ level significance are reported (to reduce the likelihood of Type II error).

Theoretically-linked measures of social and behavioral functioning were selected in order to assess the relationship between attentional cost and higher-order abilities. First, the cost variables were assessed for significant correlations with demographic variables, specifically age, IQ and language (CELF-4 Core Language scores). For the TD group, competing and validity variables were negatively associated with age, $r = -.49$, $p = .02$ and $r = -.42$, $p = .05$, respectively. For the ASD group, age was again negatively associated with competing-cost, $r = -.61$, $p = .01$, and validity-cost, $r = -.55$, $p = .02$. For the ADHD group, significant associated were found between response-salience and IQ, $r = -.70$, $p = .01$, and language, $r = -.63$, $p = .04$; due to the reflect-square-root transformation of the response-salience variable, these correlations were interpreted as positive associations. In sum, the TD and ASD groups demonstrated decreased costs associated with age. The ADHD groups demonstrated increased response-salience cost associated with higher IQ and language abilities. For variables associated with age and/or IQ and language, subsequent correlations were assessed with and without these demographic variables as a covariate.

Error variables were also assessed with respect to behavioral measures of social cognitive functioning. The single-shift joint attention subscale was associated with errors committed during the experimental task; however, the direction of findings differed between groups. For the TD group, single-shift joint attention scores were positively associate with incorrect errors ("wrong side"), $r = .56$, $p = .006$, impulsive errors, $r = .45$, $p = .03$, and total error rate, $r = .47$, $p = .04$. For the ASD group, single-shift joint attention scores were negatively associated with incorrect errors, $r = -.51$, $p = .03$, impulsive errors, $r = -.47$, $p = .04$, and total error rate, $r = -.47$, $p = .04$. For the ADHD group, single-shift joint attention scores were not significantly associated with any error variables, $r \leq .48$, $p \geq .12$. In sum, correlations with joint attention and error variables suggest that, within the TD group, impulsivity may be associated with better social skills, while, within the ASD group, impulsivity is associated with lower social skills. This finding may suggest that joint attention is a more controlled process for individuals with ASD, so that those with better cognitive control are better able to participate in joint attention interactions.

Behavioral measures of social abilities included the ADOS (ASD group only), NEPSY-II Theory of Mind, and the behavioral joint attention assessment, as well as symptom-severity rating scales (SCQ and SRS, for ASD, and the Conner's, for ADHD). Finally, parental report of executive functioning (the BRIEF) was included, to assess the relationship between attentional cost and attention in daily life. Table 8 shows the measures entered into Pearson correlation analyses.

Table 8. *Measures included in correlational analyses*

<u>Behavioral measures of social cognition</u>

ADOS (ASD only)- Severity score
NEPSY-II TOM
Experimental joint attention task (total, single-shift, and dual-shift scores)

<u>Parent-report symptom-severity scales</u>

SCQ- Total, Joint Attention Likert Total
SRS- Social Motivation, Social Awareness, Social Cognition, Total
Conners (ADHD only)- Total

<u>Executive functioning</u>

BRIEF- Shifting, Inhibition, Organization of Materials, Behavioral Regulation Index, Global Executive Composite

For the TD group, *validity* was associated with NEPSY-II TOM Total standardized scores, $r = -.46$, $p = .03$, and BRIEF (Organization of Materials) scores, $r = -.45$, $p = .03$. *Competing* was associated with BRIEF (Organization of Materials) scores, $r = -.44$, $p = .04$. Both findings were significant (p's < .05) with age as a covariate. *Social salience* was correlated with NEPSY-II TOM Total standardized scores, $r = -.43$, $p = .05$, and SRS Social Motivation, $r = .59$, $p = .003$. In both cases, a greater cost for face cues was associated with worse social skills. None of the correlations for *response salience* were significant. In sum, for TD group, increased cost for invalid cues was associated with worse TOM abilities and lower executive functioning. Increased cost for face cues was related to more difficulty with social motivation. Increased cost for competing cues was associated with better executive functioning. Table 9 shows relationships among constructs and Table 10a shows the conducted correlations for the TD group.

For the ASD group, there was a positive associated between *validity* and NEPSY-II TOM Verbal standardized scores, $r = .52$, $p = .04$, when age was entered as a covariate. Also, with age as a covariate, there was a positive association between *competing* and BRIEF Shifting scores, $r = .65$, $p = .01$. There were no significant correlations between *social salience* or *response salience* and measures of higher-order functioning. Table 10b shows correlations conducted with the ASD group. Additional analyses were conducted using the ADOS severity score, as it is considered the gold-standard measurement of ASD symptomatology; although correlations with bilateral cost variables were not significant, unilateral visual field findings emerged. ADOS severity scores were associated with RT differences between visual fields (i.e., RT to right-sided targets minus RT to left-sided targets), $r = .56$, $p = .02$, such that slower RTs to right-sided targets was associated with greater ASD symptom severity. In the right visual field, ADOS severity scores were associated with validity cost, $r = .54$, $p = .03$. In the left visual field, ADOS severity scores were associated with competing cost, $r = .52$, $p = .04$.

For the ADHD group, *validity* was positively correlated with BRIEF Inhibition, $r = .70$, $p = .01$, and Behavioral Regulation (BRI), $r = .68$, $p = .02$, scores. This suggests that increased validity cost, in this group, was associated with more problems in executive functioning. The *social salience* variable was also correlated with executive functions (BRIEF Organization of Materials), $r = .69$, $p = .01$. The lack of correlations between other cost variables and social functioning suggests that individual differences in performance on the Rainbowfish task, may been driven primarily by inattention and reduced vigilance, rather than reflecting their more general perception and interpretation of visual stimuli. Table 10c shows correlations within the ADHD group.

When comparing the pattern of correlations across groups, several points of similarity and differences emerge. For the TD group, the cost of invalid cues was associated with worse TOM and better executive functioning; the opposite was found for the ASD group, with increased cost being associated with better TOM. The implication of these findings will be discussed in more detail in the follow Discussion section; however, it is important to highlight that the meaning of invalid-cost may be very different between groups. For the cost of *competing* cues, both the ASD and TD groups showed a reduction in cost with age. For the ASD groups, greater cost of competing cues was associated with worse executive functioning, while the opposite was found for the TD group. For the cost of *socially-salient* (i.e., face) cues, greater cost for face cues was associated with worse TOM and social motivation for the TD group and with worse executive functioning in the ADHD group. No significant correlations with social cognitive measures were found within the ADHD group.

Table 9. *Summary of direction of significant cost-variable group correlations.*

	ASD (n = 19)	ADHD (n = 12)	TD (n = 23)
Validity[a]	↑ TOM (r = .52, p =.04)	↓ Executive Functioning (r = .70, p = .01; r = .68, p = .02)	↓ TOM (r = -.46, p =.03) ↑ Executive Functioning (r = -.45, p =.03)
Competition[b]	↓ Executive Functioning (r = .65, p =.01) [d]		↑ Executive Functioning (r = -.44, p =.04)
Social Salience[c]		↓ Executive Functioning (r = .69, p = .01)	↓ TOM (r = -.43, p =.05) ↓ Social Motivation (r = .59, p =.003)

[a] Validity cost = invalid cue RT minus valid cue RT.
[b] Competition cost = competing cue RT minus non-competing cue RT.
[c] Social Salience cost = face cue RT minus arrow cue RT.
[d] ↑ indicates a positive association between constructs, while ↓ indicates a negative association; these symbols aim to facilitate across-group comparisons. Directional arrows account for the SRS and BRIEF having higher scores reflecting more impaired performance. All presented correlations are significant at the $p < .05$ level.

Table 10a. *Correlations: cost variables and measures of social functioning (TD).*

	Validity[a]	Competition	Response-Salience[b]	Social-Salience
NEPSY TOM Total	**-.46***	-.31	-.12	**-.43***
NEPSY TOM Verbal	-.19	-.11	-.10	-.33
Joint Attention	.09	-.10	-.11	-.17
SCQ- Total	-.09	-.20	.06	-.04
SCQ- Likert Total	-.21	-.21	.18	.01
SRS- Motivation	.26	.13	.14	**.59***
SRS- Awareness	.16	.02	.08	.17
SRS- Cognition	**.62***	.31	-.10	.38
SRS- Total	.35	.15	-.04	.36
BRIEF- Shift	-.16	-.23	.13	-.35
BRIEF- Inhibition	-.11	-.15	.02	-.31
BRIEF- Org.[c]	**-.45***	**-.44***	.19	.02
BRIEF- BRI	-.26	-.26	.06	-.24
BRIEF- GEC	-.29	-.28	-.06	-.17

* and bold = $p < .05$
[a] Validity cost variable was square-root transformed.
[b] Response-salience cost variable was reflect square-root transformed.
[c] BRIEF Organization of Materials

Table 10b. *Correlations: cost variables and measures of social functioning (ASD).*

	Validity[a]	Competition	Response-Salience[b]	Social-Salience
ADOS- Severity	.37	.47§	.01	.07
NEPSY TOM Total	.09	-.13	-.24	.39
NEPSY TOM Verbal	**.52*[d]**	-.02	-.14	.33
Joint Attention	.001	.05	-.16	-.11
SCQ- Total	-.22	.05	-.37	.07
SCQ- Likert Total	.15	.12	-.38	-.04
SRS- Motivation	.16	.46§	-.49§	-.03
SRS- Awareness	.22	.39	-.66^	.17
SRS- Cognition	.02	.25	-.44	-.09
SRS- Total	.23	.48§	-.42	.07
BRIEF- Shift	-.33	**.65*[d]**	-.12	-.24
BRIEF- Inhibition	-.01	.19	-.22	.33
BRIEF- Org.[c]	-.02	.05	.21	-.32
BRIEF- BRI	-.14	.29	-.24	-.11
BRIEF- GEC	-.18	.19	-.13	-.19

* and bold = $p < .05$, § = $p < .10$, ^ denotes an artifact
[a] Validity cost variable was square-root transformed.
[b] Response-salience cost variable was reflect square-root transformed.
[c] BRIEF Organization of Materials
[d] Age entered as a covariate, based on preliminary analyses

Table 10c. *Correlations: cost variables and measures of social functioning (ADHD).*

	Validity[a]	Competition	Response-Salience[b]	Social-Salience
Conners- Total	.01	.07	-.001	.42
NEPSY TOM Total	-.36	-.16	-.03	.03
NEPSY TOM Verbal	-.34	.00	-.20	.04
Joint Attention	.14	.11	-.32	-.18
SCQ- Total	.08	-.09	-.04	.07
SCQ- Likert Total	.05	.33	-.20	.48
SRS- Motivation	-.32	-.15	-.15	.54
SRS- Awareness	.37	.01	-.19	.17
SRS- Cognition	-.16	-.004	-.15	.59§
SRS- Total	.04	.02	-.10	.49
BRIEF- Shift	.48	-.10	.38	.16
BRIEF- Inhibition	**.70***	.17	.34	.007
BRIEF- Org.[c]	-.38	.39	.08	**.69***
BRIEF- BRI	**.68***	-.14	.52§	.03
BRIEF- GEC	.27	.10	.22	.47

* and bold = $p < .05$, § = $p < .10$
[a] Validity cost variable was square-root transformed.
[b] Response-salience cost variable was reflect square-root transformed.
[c] BRIEF Organization of Materials

Eye Tracking Analyses

Eye movements were tracked using an EyeLink 1000 desktop-mounted eye tracker, which recorded eye gaze without restricting head or body movements with an accuracy of better than one degree. Data from two participants was unusable due technical errors, resulting in groups of 21 (TD), 19 (ASD), and 12 (ADHD). As with previous analyses, the two participants with extremely high error rates were removed. Across all analyses, transformed variables were used in order to utilize parametric analyses; non-parametric analyses were run with raw variables and, in all cases, the findings were unchanged.

Trials with lost fixations. The number of trials with lost fixations was tracked, in order to analyze the number of trials that were removed for lost fixations between groups. Lost fixation variables were defined as the number of (1) trials with lost fixations before the cue was presented, (2) trials with lost fixations after the target was presented, and (3) trials with lost fixations during the critical period (i.e., in between cue and target presentation). Only the later trials were removed from analyses, as previously described in the Methods section. The number of lost fixations was generally low across groups. Out of 408 trials, the *M* and *SD* for number of lost fixations during the *critical period* was 4.1 (5.9) for the TD group, 4.9 (6.2) for the ASD group, and 3.5 (5.2) for the ADHD group. There were no group differences in the numbers of lost fixations for any time period, all F's < 1.31, p's > .28.

Anticipatory Fixations. Anticipatory fixations (AF) were defined as fixations beginning after the cue presentation (400 ms) and before the target presentation (1000 ms), during which the participant looked to the anticipated target location based on the information provided in the cue. On the right side of the screen, areas (i.e., regions of interest, ROI) were defined as the broad right-side of the screen (i.e., ROI 5) or the restricted target area (i.e., ROI 8). In the left visual field, similar areas were identified (i.e., ROI 3 representing the broad left side and ROI 6 representing the restricted target area). The following analyses are reported using ROIs 3 and 5, to account for both sets of interest areas (refer to Figure 3 for a visual representation of the target locations). AFs are presented as proportion scores (i.e., the number of trials with an AF to the anticipated location divided by the number of usable trials in a condition), in order to compare across cue types and target locations. Because they were non-normally distributed (i.e., positively skewed), all AF variables were square-root transformed in order to utilize parametric analyses.

One-Way ANOVAs probed group differences in AFs as a function of condition (i.e., face, arrow, competing, non-competing) and visual field location. Across all cue types and target locations, the ASD and ADHD groups consistently demonstrated more AFs than the TD group, with p's $< .05$. Table 11 shows group means for cue trials (to ROIs 5 and 3) and results for baseline trials. The ASD and ADHD groups were not significantly different on any cue comparison, with p's $> .33$. The only comparison between the ASD and ADHD group reaching significance suggested that the ADHD demonstrated significantly more AFs to the target location on baseline trials than the ASD group, $t(29) = -2.47$, $p = .02$. These findings indicate that the number of AFs may be related to general inattention, especially in the ADHD group, rather than an ASD-specific issue with cue evaluation.

Table 11. *AF group means by cue type and target location for the general target sides (Interest areas 5 and 3).*

	ASD (n = 19)	ADHD (n = 12)	TD (n = 21)	F	p	η^2_p	Post-hoc comparisons[d]
Right-ROI[abc]	.27 (.25); .01-.72	.23 (.18); .00-.47	.13 (.15); .00-.46	2.88	.07	.10	TD < ASD
Face cues	.24 (.23); .00-.75	.22 (.17); .00-.43	.12 (.14); .00-.48	2.69	.08	.10	TD < ASD
Arrow cues	.30 (.26); .02-.80	.24 (.21); .00-.53	.14 (.15); .00-.45	3.20	.05	.12	TD < ASD
Competing cues	.27 (.24); .02-.70	.26 (.20); .00-.53	.15 (.17); .00-.55	2.29	.11	.09	TD < ASD
Non-competing cues*	.28 (.26); .00-.78	.20 (.17); .00-.50	.12 (.13); .00-.44	3.47	.04	.12	TD < ASD
Left-ROI*	.17 (.21); .01-.63	.19 (.17); .00-.55	.08 (.11); .00-.41	3.10	.05	.11	TD < ASD, ADHD
Face cues*	.15 (.19); .00-.57	.16 (.15); .00-.51	.06 (.09); .00-.40	3.63	.04	.13	TD < ASD, ADHD
Arrow cues	.20 (.23); .01-.70	.23 (.20); .00-.60	.10 (.12); .00-.48	2.95	.06	.11	TD < ASD, ADHD
Competing cues	.15 (.19); .00-.62	.20 (.18); .00-.55	.08 (.11); .00-.40	2.30	.11	.09	TD < ADHD
Non-competing cues*	.19 (.22); .00-.69	.19 (.17); .00-.55	.08 (.10); .00-.41	3.46	.04	.12	TD < ASD, ADHD
Baseline Trials[e]	.16 (.19); .00-.70	.26 (.19); .00-.63	.15 (.18); .00-.58	2.06	.14	.08	TD, ASD < ADHD

** $p < .001$ *$p < .05$ *Note:* Data are presented as *M (SD); Range.*
[a] ROI = Region of interest; Right-ROI, or ROI-5, is in the right visual field, Left-ROI, or ROI-3, is in the left visual field.
[b] AFs presented as raw proportion scores; raw variables were square-root transformed in order to utilize parametric analyses.
[c] Group differences (comparing all groups) in AFs were calculated using a One-Way ANOVA.
[d] > or < indicate significant group differences at the $p < .05$ level
[e] Proportion scores for baseline (no-cue) trials collapse across visual fields.

AFs and the Main Effect of Directional Cue (versus no-cue, baseline trials). Repeated-Measures MANOVAs assessed for main effects of cue compared to baseline (i.e., no cue) trials. When comparing AFs to the general target sides (collapsing across right- and left-visual fields) on trials with a directional cue, to AFs to the broad target sides during baseline trials, there were no main effects of the directional cue, $F(1, 51) = .041$, $p = .84$. There was no group effect, $F(2, 51) = 1.91$, $p = .16$. The group by condition interaction effect was significant, $F(2, 51) = 3.32$, $p = .04$. Post-hoc analyses revealed significant interaction effects between the ASD and ADHD groups, $F(1, 30) = 4.20$, $p = .05$, and between the TD and ASD group (at the trend level), $F(1, 39) = 3.63$, $p = .06$. The TD and ADHD groups were not significantly different, $F(1, 33) = .44$, $p = .51$. These analyses indicate that the TD and ADHD groups demonstrated more AFs on baseline trials than cue trials (.30 versus .27 and .46 versus .39, respectively); the ASD group, in contrast, showed more AFs on cue trials than baseline trials (.41 versus .33), although this contrast was not statistically significant, $t(18) = 1.47$, $p = .16$.

When separating cue trials by visual field, there were no main effects for the left side (i.e., ROI 3), $F(1, 49) = 1.47$, $p = .23$, nor for the right side (i.e., ROI 5), $F(1, 49) = 2.28$, $p = .14$. These findings again indicated that participants did not make significantly more AFs when given a directional cue. There was a trend level group by target location interactions for the right visual field, $F(2, 49) = 3.06$, $p = .056$ (i.e., ROI 5). The ASD group again had more AFs on cue trials, compared to baseline trials, than the TD group. There was no group by target location interaction for ROI 3, $F(2, 49) = 1.81$, $p = .17$, when comparing all three groups; however, trend-level interactions when making two-group comparisons, p’s < .10, indicated that both the TD and ADHD groups tended to show more AFs on baseline trials than cue trials when compared to the ASD group (when isolating trials to the left visual field).

In sum, the ASD group was the only group that showed more AFs for cue trials than for no-cue (i.e., baseline) trials. The TD and ADHD groups showed the reverse pattern. Because there was no main effect of cue (i.e., the groups did not shift to the target location more when given a cue than when there was no cue at all), comparing AFs by cue type may not represent meaningful differences with respect to participants' evaluation of the cue.

AFs to the right- or left-side of the screen. Paired-sample t-tests assessed for within-group differences in AFs for cues directing attention to the right- or left-visual field. When collapsing across cue types, both the ASD and TD groups showed more AFs to the right-side of the screen (interest area 5) than the left-side of the screen (interest area 3), $t(18) = 2.69$, $p = .02$ and $t(20) = 2.78$, $p = .01$, respectively. The ADHD group did not demonstrate a location difference, $t(11) = .47$, $p = .48$. This pattern of more right-sided AFs than left-sided AFs (to the general target sides) remained for the TD and ASD groups for both face and arrow cues, p's < .05, and for both competing and non-competing cues, p's < .08 for the TD group and p's < .04 for the ASD group. The ADHD group did not show an effect for any cue type, p's > .18 (refer to Table 11). In sum, these findings suggest a preference for scanning the right visual field for the TD and ASD groups or an inability to inhibit an inappropriate response when the left hemisphere is supporting response selection.

Cue fixation. The amount of time participants fixated on the cue was measured as a secondary assessment of cue engagement. As described in the Methods section, visual fixations on the cue were presented as proportion scores, in order to compare fixation time across cue types. Proportion of time spent fixated on the cue ("cue fixation") variables were reflect square-root transformed because the variable was non-normally distributed (i.e., positively skewed); analyses were run with the raw variables using non-parametric techniques and findings were unchanged. A cue fixation was defined for fixations in the central region of the screen (including the entire vertical center, ROI 4). One-Way ANOVAs probed for group differences in the proportion of time the participant spent fixated on the cue. There were no significant group differences in overall cue fixation for any cue type, F's < 1.33 and p's > .27. This finding suggests that, despite group differences in RT and in visual scanning, the amount of time the participants are spending looking at the cues did not differ across groups (overall group means were .72, .66, and .75 for the ASD, ADHD, and TD groups, respectively). The interpretation of these findings highlights the separation of attention and eye fixation, supported in the literature, and sheds light on the mechanisms underlying previous findings, to be discussed in more detail in the Discussion section.

Discussion

The present study was designed to better understand how older children and adolescents with autism spectrum disorders (ASD), attention-deficit/hyperactivity disorder (ADHD), and typical development (TD) perceive and respond to directionally-meaningful visual information. The aim of this study was to evaluate how individuals with ASD respond to different types of directional cues, to identify the role of low-level attentional mechanisms in higher-order social and cognitive functioning. Individuals with ASD were compared to those with TD and ADHD to identify differences in visual attention for individuals with and without social cognitive deficits, to better understand atypical developmental trajectory in ASD and to target points for early intervention. In line with the *experience-expectant model* of neural development (Mundy & Burnette, 2005), early identification and amelioration of visual attention abnormalities could change the way children with ASD interact with their visual worlds and thereby change their trajectory of social development.

This project was motivated by the extensive literature on early social visual attention (i.e., joint attention) and its crucial role in early development. Joint attention differentiates children with ASD from children with other developmental delays (Ventola et al., 2007), and is the strongest predictor of theory of mind (Charman et al., 2000) and language development (Tomasello & Farrar, 1986). Joint attention deficits in ASD persist through adolescence (Bean & Eigsti, 2012) and are likely a core feature of social cognitive disorders. Importantly, and despite the pathognomonic nature of joint attention in ASD, previous research suggests that joint attention is not *absent* in ASD and may respond to changes in visual cues (Presmanes, Walden, Stone, & Yoder, 2007).

Previous studies of visual attention in ASD have used a variety of stimuli, methodological tools, and inclusion criteria. As a result, the literature is inconsistent. Studies have reported both intact (e.g., Renner et al., 2006) and abnormal (e.g., Wainwright-Sharp & Bryson, 1993) cue evaluation; and both sticky (e.g., Landry & Bryson, 2004) and reduced (e.g., Van der Geest et al., 2001) attentional engagement. A number of factors are hypothesized to influence performance, including behavioral inhibition, cognitive control, social salience, and visual-field laterality. These factors have not been systematically controlled in most prior studies, and the variation in methods and participant characteristics has hindered our identification of patterns. Finally, no studies simultaneously evaluated multiple visual attentional processes. The current study was designed to assess these multiple aspects of visual attention simultaneously to determine (1) if high-functioning individuals with ASD demonstrate deficits in visual attention and (2) whether specific deficits are associated with "real-world" social abilities.

To address the first goal of assessing group differences in low-level visual attention, a modified Posner-style paradigm was employed (Posner, 1980). The first manipulation assessed for group differences in *cue evaluation*, defined as the relative speed of responding to valid and invalid directional cues (a face or an arrow). If individuals do not make use of information from directional cues, there will be little difference in RT. Here, the ASD participants had significantly greater validity cost than the TD group; the ADHD group did not differ from either group. This finding held for short ("non-competing") cues lasting only 150 ms, suggesting that individuals with ASD make use of even brief directional cues. Not only did the ASD group note the predictive value of directional cues, they had *greater* difficulty than TD peers in overriding that information when cues were invalid. Post-hoc analyses supported that this exaggerated validity cost in the ASD group was primarily driven by arrow cues (consistent with previous research; Vaidya et al., 2011). A greater validity cost in ASD is consistent with literature suggesting that children with autism spectrum disorders are slower to orient in response to cues in peripheral vision (e.g., Townsend, Courchesne, & Egass, 1996) and that individual slowing correlates with the degree of cerebellar hypoplasia (Harris, Courchesne, Townsend, Carper, & Lord, 1999). Additionally, an exaggerated validity cost for arrows, as opposed to social/face cues, supports a difficulty overriding invalid, meaningful information, while reduced engagement in social/face cues could explain the lessened difficulty overriding those directional cues.

The second experimental contrast assessed *disengagement*, defined as the difference between competing and non-competing cues. Individuals with more difficulty in attention shifting should show greater slowing when cues remained on screen simultaneously with the target. Contrary to expectations, the ASD group demonstrated a significantly *smaller* disengagement cost than either the TD or ADHD group. Although "sticky" attention (i.e, disengagement concerns) is a more common in younger children (e.g., Zwaigenbaum et al., 2005), this finding of reduced engagement is consistent with previous research with individuals with ASD with a mean age of 10 years (van der Geest et al., 2001). A group by condition interaction between the ASD and TD group held for both social (face) and nonsocial (arrow) cues. These findings suggest that the ASD group was less engaged by the cue, showing almost no response cost (a mean of 4 ms) given competing cues. In contrast, the TD group continued to attend to the competing cues, resulting in a response cost of 27 ms on average. The discrepancy between these findings (from individuals with mean age of 12 years) and the cardinal findings from Landry and Bryson (2004), suggesting "sticky attention" (in ASD in children with a mean age of six years), could reflect, in part, participant age; older individuals may have learned to compensate via a top-down approach limiting initial cue engagement. Also, the 2004 study used flashing lights, rather than directional cues; there is likely a difference in the directional salience for such a visual stimulus.

To assess the role of social factors in visual attention, a third manipulation assessed for group differences in responding to socially salient directional information (i.e., *social salience*), operationalized as the relative RT difference for social (face) and nonsocial (arrow) cues. Inefficient evaluation of social information would be reflected in slowing for face cues. The ASD group trended to demonstrate a slowing for arrows relative to faces, to a greater degree than their TD peers; the ADHD group did not differ from the TD or ASD groups. While the TD group responded to face and arrow cues similarly (a difference of 1 ms on average), the ASD group responded an average of 10 ms faster to face cues. While this interaction was a trend, $p = .11$, it suggests that the ASD group may be less engaged by these cues and/or decreased cue engagement overall.

The fourth manipulation assessed for group differences in behavioral inhibition (i.e., *response salience*), defined as the relative slower RT for high-salience (i.e., four preceding valid cues) and low-salience (i.e., two preceding valid cues) invalid cues. Difficulty overriding a salient behavioral response should be reflected in a relative slowing for high-salience cues. Current results show that all three groups demonstrated an increased cost for high-salience cues; however, there was no interaction effect, indicating that the groups all had a similar response salience cost. Individuals with ADHD, who can be impulsive in some contexts (e.g., go-nogo task performance; Bezdjian, Baker, Lozano, & Raine, 2009), might be expected to be more impacted by response salience. That they were not more affected may reflect that this particular manipulation was so strong, that all groups were susceptible; alternatively, this may reflect task variables, including the use of an overly subtle measure of response salience (two- versus four-preceding cues) or a lack of power (due to small sample sizes) to detect slight group differences.

To better understand these findings, the experimental contrasts were assessed separately for right and left visual fields, including only right-handed participants (who responded with the right hand). Overall, across groups, the main effects of *validity* and *competing* cues were present in both visual fields. The main effect for *response salience* was present for right-sided targets only, while the main effect for *social salience* was present for left-sided targets only. These findings suggest that overarching attentional principles such as cue evaluation and disengagement, while having neurologically specific underpinnings (e.g., Fan et al., 2009), may recruit bilateral structures in order to interact with environmental stimuli. For response salience, this manipulation was more subtle and, therefore, may be more susceptible to competing environmental processes and, therefore, only clearly seen in the visual field contralateral to the hemisphere supporting the response hand. The social salience finding could reflect a tendency to process meaningful visual stimuli more often with right-lateralized structures, making left-visual field responses more readily available.

Assessing group by condition interactions, the ADHD group performed more similarly (i.e., fewer group by condition interactions) to the TD group when targets appeared in the left visual field than when they appeared in the right visual field. This pattern implicated a left hemispheric abnormality in primary inattention. In contrast, the ASD group demonstrated dramatically different performance than the TD group in both visual fields, indicating a more global abnormality in interacting with visual information.

As for the relationship between experimental manipulation cost and measures of “real-world,” higher-order abilities, there were similarities and differences between groups. For *validity*, increased cost in the TD group was associated with worse theory of mind and better executive functioning; the opposite was found for the ASD group, with increased validity cost associated with *better* theory of mind. When isolating visual fields, increased cost for invalid cues in the right visual field, as well as slower RT to the right visual field more generally, were associated with more *severe* ASD symptomatology. These findings suggest that the construct of "validity cost" may represent different skill sets in groups with and without social deficits: in the TD group, slower reaction times to invalid cues may represent attentional stickiness. For the ASD group, in general, individuals who strive to engage more deeply with visual cues may have developed better social insight; however, deficits in efficiently allocation attention to the right visual field, as reported by previous research (e.g., Vlamings et al., 2005) may represent an ASD-related concern. For *competing* cues, the TD and ASD group again showed opposite patterns. Greater competing costs were correlated with *better* executive functioning in TD but with *worse* executive functioning and more severe symptomatology in ASD. These findings suggest that, for TD participants, the more engaged an individual is in the cue, the better control of their cognition/behavior they are likely to show in general; while for ASD participants, the longer one takes to disengage from the central cue, the more cognitive control issues they are likely to demonstrate in the real world.

For *social salience*, the anticipated relationship between increased cost for social cues (i.e., as a marker of inefficiency in reading social information) and *worse* theory of mind and social motivation was true for the TD group, while the ADHD group showed a correlation with *worse* executive functioning. The lack of relationship between social-salience cost and higher-order functioning in the ASD group could reflect the overwhelming influence of domain-general engagement and attention allocation, rather than a social-specific mechanism influencing interactions with visual information in the real world.

For the ADHD group, the lack of significant associations between visual attention mechanisms and social-cognitive functioning could be related to the dramatic variability in group performance and the overwhelming influence of poor executive functioning. This interpretation is consistent with preliminary results indicating that the ADHD group was more variable in their overall RT, which is an established marker of clinical inattention (e.g., Leth-Steensen, Elbaz, & Douglas, 2000). The inclusion of this primary-inattention comparison group enabled us to probe the role of inattention in the Posner task, helping to clarify ASD-specific attentional abnormalities. Importantly, no group findings suggested a speed-accuracy trade-off; therefore, differences in RT likely reflect attentional processes within and between groups.

Finally, eye fixations were tracked as an additional marker of visual attention. Current results demonstrate no group differences in the amount of time participants spent visually fixated on the central cue. This finding highlights the discrepancy between eye fixation and attention allocation noted in the literature and supported in the current study (i.e., no group differences in visual fixation time, with significant group differences in attentional disengagement patterns). Anticipatory fixations (AFs) to the target location were assessed as a secondary measure of cue evaluation, under the hypothesis that a greater number of AFs may reflect an individual's ability to make use of information from visual cues. The ASD group demonstrated slightly more AFs for cue trials than for no-cue trials, $p = .16$, whereas the TD and ADHD groups tended to have more AFs for baseline (no-cue) trials than cue trials. This finding regarding the main effect of AFs during cue versus no-cue trials could be related to several factors. First, participants were instructed to remain fixated on the cue and to “catch” the target “out of the corner” of their eye, so the tendency for participants who shifted visual fixation away from the cue, this findings could relate to a reduced ability to comply with task instructions. This reduced ability could be the result of a reduced understanding or memory for the instructions, reduced cognitive control (reflected in an inability to override the reflective pull of a directionally-meaningful cue) or, in contrast, an increased directional salience of the cue compared to the other groups. Second, this finding could reflect the increased engagement of the TD and ADHD group on the cue, and therefore, reduced likelihood of moving visual fixation away from the central visual space. Third, ASD group abnormalities in volitional eye movements have been documented (Takarae et al., 2004); this finding could be related more to the mechanics of eye movements rather than attentional processes.

Overall, the results from this study indicate that individuals with ASD, when compared to individuals with TD and ADHD, have visual attention abnormalities that may impact their ability to successfully interact with visual information in the environment. These findings speak to the basis of visual attention differences in ASD. Rather than a primarily social explanation, such as an issue with relatedness or theory of mind initially (Leekam & Moore, 2001), these findings are likely related to bottom-up inefficiencies in visual attention (Leekam & Moore, 2001; Nation & Penny, 2008). The results, therefore, have implications for social functioning: although individuals with ASD were successful in making use of the predictive value of directional cues, they appeared to be less engaged by the visual information than their peers and less able to reallocate and modify their attention after it was directed. Consistent with this interpretation, a greater understanding of cue predictiveness in the ASD group was associated with better theory of mind, while a difficulty in disengaging from competing cues was associated with worse cognitive control in the real world. This suggests that the more that individuals with ASD engage with visual cues, the better they will be able to use that information to make decisions and modify their behavior. This finding is relevant for early intervention. That is, most ABA approaches effectively work to increase a child's engagement with visual social information and reward them for their level of engagement and adequately using that information to inform their behavior by enhancing their motivation to do so.

The current study has several limitations. First, although the results of this study have implications for development and change over time, the cross-sectional design limits the conclusions that can be drawn about the causal relationship between visual attention and higher-order functioning variables. A prospective design would address this issue. Second, the moderately small sample sizes in this study, particularly in the ADHD group, provided adequate power (80%) for the main analyses, but may have limited the ability to find effects of more subtle manipulations (e.g., response salience interactions). Third, although this study sample spanned a large age range, the homogeneity in level of functioning may have limited the amount of variability seen within groups. Excluding individuals with intellectual impairment limited the confounding influence of difficulty with understanding task instructions; however, the inclusion of more severely affected individuals may or may not alter the findings and make the assumptions of this study more generalizable to the general population of individuals with ASD. Finally, as described in more detail above, the task instructions to remain fixated on the central cue likely confounded eye-tracking results and altered our ability to assess the natural timecourse of eye movements, thus limiting the interpretation of those analyses.

In conclusion, this study evaluated multiple aspects of visual attention within the same task and the same group of participants, in order to assess for the relative contribution of low-level attention mechanisms to social abilities. Results suggest that older children and adolescents with social impairments interact differently with domain-general visual information than individuals with typical social development. As previously described, social interactions require the integration of many simultaneous events, including *identifying* social stimuli, *interpreting* information from the interaction, and *carrying out* an appropriate response. The results from this study indicate that reduced engagement in visual information may limit individuals with ASD's ability to identify relevant visual stimuli. Encouragingly, once attention is engaged, individuals with ASD appear able to interpret the directional cues as meaningful. However, results suggest that individuals with ASD may struggle to use this information to efficiently modify their behavioral response. These findings in the context of a controlled, experimental paradigm are likely exacerbated in the complex, dynamic nature of real-life social situations.

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